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ANALYSIS OF CONSOLIDATING
NAVAL AVIATION DEPOTS

by

Donald J. Krentz

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by

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ABSTRACT

This thesis is a study of the Naval Aviation Depot streamlining and consolidation as a result of Defense Management Review Decision (DMRD) 908. The Navy has conducted extensive economic analysis of DMRD 908 but no study of the production operations has been accomplished. This thesis examines the consolidation of the F/A-18 aircraft F404 engine and module repair at Naval Aviation Depot Jacksonville NADEP JAX), Florida. The major thrust of the thesis is the application of queueing theory and simulation techniques to investigate the effect of production consolidation on the engine and module repair operation at NADEP JAX. The study examines how engine and module turn-around-time (TAT) and work-in-process (WIP) would change when production resources remain constant and the number of engines repaired at the facility increases. The thesis concludes that if all F404 engine and module depot level repair is consolidated at NADEP JAX without an increase in production resources, TAT and WIP will increase and available capacity for surge requirements will be limited.

TABLE OF CONTENTS

I. INTRODUCTION 1

A. OBJECTIVES 1

B. HISTORY 3

C. ENGINE OVERHAUL/REWORK 8

D. CAPACITY UTILIZATION 12

E. THESIS OBJECTIVE 13

II. BACKGROUND 15

A. DESIGNING THE EXPERIMENT 15

B. HYPOTHESIS 17

1. Hypothesis Statement 17

2. Approach 18

C. QUEUEING THEORY 19

1. Queueing Models 19

2. Little's Flow Equation 20

3. Classifying Queueing Models 21

D. INFORMATION COLLECTION 22

1. Interarrival Data 23

2. TAT and Repair Time 23

E. SIMULATION 26

F. RESULTS FROM THE QUEUEING MODEL AND SIMULATION MODEL 30

III. MODEL DESIGN 32
A. ASSUMPTIONS 32
B. DATA 34
C. QUEUEING MODEL (Basic Model) 35
1. Model Definition 35
2. Queueing Model Formulas 35
3. Basic Model Data Description 36
a. Interarrival Time 36
b. Repair Time 36
D. SIMULATION MODEL 37
1. Model Frame 38
2. Experimental Frame 40
a. TALLIES Element 40
b. DSTAT Element 41
c. Replication 41

IV. ANALYSIS 43
A. QUEUEING MODEL ANALYSIS 43
1. NADEP JAX (FY-90 and 91) 46
2. NADEP JAX (Desert Storm) 48
3. NADEP JAX FY-92 FORECAST 50
B. SIMULATION ANALYSIS 52
1. NADEP JAX, FY-90 and 91 Simulation 54
2. NADEP JAX, Desert Storm Simulation 58
3. NADEP JAX, FY-92 Simulation 61

V. CONCLUSIONS AND RECOMMENDATIONS 66

A. CONCLUSIONS 67

B. RECOMMENDATIONS 69

LIST OF REFERENCES 73

APPENDIX A 75

A. FY-90 AND 91 INTERARRIVAL DATA 75

B. FORECAST INTERARRIVAL DATA 77

APPENDIX B 79

APPENDIX C 82

A. TRANSITION PATTERNS FY-90 AND 91 83

B. TRANSITION PATTERNS DESERT STORM 87

C. TRANSITION PATTERNS FY-92 FORECAST 91

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LIST OF TABLES

TABLE I.1 ENGINE DEPOT ALIGNMENT PLAN, OPTION 1 . . 10

TABLE I.2 ENGINE DEPOT ALIGNMENT PLAN, OPTION 2 . . . 10

Table IV.1 NADEP JAX INTERARRIVAL TIMES ($1/\lambda$) 44

TABLE IV.2 NADEP NORIS INTERARRIVAL TIME ($1/\lambda$) 44

TABLE IV.3 NADEP JAX TURN-AROUND-TIME (TAT) AND REPAIR TIMES 45

TABLE IV.4 NADEP JAX REQUIRED REPAIR TIME TO MEET THE TARGET TAT 46

TABLE IV.5 NADEP JAX CAPACITY UTILIZATION COMPARISON TO MAINTAIN THE TARGET TAT 47

TABLE IV.6 NADEP JAX WIP COMPARISON TO MAINTAIN THE TARGET TAT 48

TABLE IV.7 NADEP JAX REQUIRED REPAIR TIME COMPARISONS TO MEET THE TARGET TAT (DESERT STORM) 48

TABLE IV.8 NADEP JAX CAPACITY UTILIZATION COMPARISON TO MAINTAIN THE TARGET TAT (DESERT STORM) . . 49

TABLE IV.9 NADEP JAX WIP TO MAINTAIN THE TARGET TAT . 49

TABLE IV.10 FY-92 FORECAST ENGINE AND MODULE REQUIREMENTS AND INTERARRIVAL TIMES 50

TABLE IV.11 NADEP JAX FY-92 FORECAST 51

TABLE IV.12 FY-90 FORECAST REPAIRS vs ACTUAL REPAIRS . 51

TABLE A.1 NADEP JACKSONVILLE INDUCTIONS FROM 1st QUARTER 1990 (1Q90) TO 3rd QUARTER 1991 (3Q91) . . . 75

TABLE A.2 NADEP NORTH ISLAND INDUCTIONS FROM 1st QUARTER 1990 (1Q90) TO 3rd QUARTER 1991 (3Q91) . . . 75

TABLE A.3 NADEP JAX MEAN INTERARRIVAL TIME ($1/\lambda$) . . 76

TABLE A.4 NADEP NORIS MEAN INTERARRIVAL TIME ($1/\lambda$) . . 77

TABLE A.5 FY-92 FORECAST ENGINE AND MODULE REQUIREMENTS AND MEAN INTERARRIVAL TIMES 78

TABLE B.1 NADEP JAX TURN-AROUND-TIME (TAT) AND REPAIR TIMES 80

TABLE B.2 NADEP JAX REPAIR TIME $1/\mu$ AFTER CONSOLIDATION 81

LIST OF FIGURES

Figure 2.1 NADEP JAX FY-90 Engine TAT Frequency Distribution 25
Figure 4.1 SAMPLE SIMAN OUTPUT FOR FY-90 and 91 MODEL 56
Figure 4.2 NADEP JAX F404 TAT FY-90 and 91 57
Figure 4.3 NADEP JAX F404 WIP FY-90 and 91 57
Figure 4.4 NADEP JAX F404 TAT Desert Storm 60
Figure 4.5 NADEP JAX F404 WIP Desert Storm 60
Figure 4.6 NADEP JAX F404 TAT FY-92 Forecast 62
Figure 4.7 NADEP JAX F404 WIP FY-92 Forecast 62
Figure 4.8 NADEP JAX HPC TAT FY-92 Forecast 63
Figure 4.9 NADEP JAX HPC WIP FY-92 Forecast 63
Figure C.1 NADEP JAX FAN TAT FY-90 and 91 83
Figure C.2 NADEP JAX FAN WIP FY-90 and 91 83
Figure C.3 NADEP JAX HPC TAT FY-90 and 91 84
Figure C.4 NADEP JAX HPC WIP FY-90 and 91 84
Figure C.5 NADEP JAX HPT TAT FY-90 and 91 85
Figure C.6 NADEP JAX HPT WIP FY-90 and 91 85
Figure C.7 NADEP JAX LPT TAT FY-90 and 91 86
Figure C.8 NADEP JAX LPT WIP FY-90 and 91 86
Figure C.9 NADEP JAX FAN TAT Desert Storm 87
Figure C.10 NADEP JAX FAN WIP Desert Storm 87
Figure C.11 NADEP JAX HPC TAT Desert Storm 88
Figure C.12 NADEP JAX HPC WIP Desert Storm 88
Figure C.13 NADEP JAX HPT TAT Desert Storm 89

Figure C.14 NADEP JAX HPT WIP Desert Storm 89

Figure C.15 NADEP JAX LPT TAT Desert Storm 90

Figure C.16 NADEP JAX LPT WIP Desert Storm 90

Figure C.17 NADEP JAX FAN TAT FY-92 Forecast 91

Figure C.18 NADEP JAX FAN WIP FY-92 Forecast 91

Figure C.19 NADEP JAX HPC TAT FY-92 Forecast 92

Figure C.20 NADEP JAX HPC WIP FY-92 Forecast 92

Figure C.21 NADEP JAX HPT TAT FY-92 Forecast 93

Figure C.22 NADEP JAX HPT WIP FY-92 Forecast 93

Figure C.23 NADEP JAX LPT TAT FY-92 Forecast 94

Figure C.24 NADEP JAX LPT WIP FY-92 Forecast 94

I. INTRODUCTION

A. OBJECTIVES

The Navy has two Naval Aviation Depots (NADEP), North Island (NORIS), California and Jacksonville (JAX), Florida capable of complete overhaul and repair of the F/A-18 aircraft engine, the F404-GE-400. Streamlining efforts by the Department of Defense (DoD) and the Department of the Navy to save money have resulted in the consolidation of the overhaul/repair of F404 engines and modules[1] at one depot, NADEP JAX.

Conversations with Naval Aviation Depot Operations Center (NADOC) Patuxent River, Maryland (Hill, 1991), Naval Air Systems Command (NAVAIRSYSCOM) Code 423 (Heilman, 1991a), and the engine production supervisor (Harpster, 1991) at NADEP JAX indicate that all F404 engines and modules previously scheduled for overhaul/repair by a combined NADEP JAX and NADEP NORIS effort, will be assigned by NAVAIRSYSCOM to NADEP

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[1] The F404-GE-400 engine is modular in construction. Six modules make up an engine. These modules are the Fan, High Pressure Compressor (HPC), Combuster, High Pressure Turbine (HPT), Low Pressure Turbine (LPT), and Afterburner. The NADEP does minimal combuster and afterburner repair. This paper will deal only with the complete F404 engine, the Fan, HPC, HPT, and LPT modules.

JAX for overhaul/repair[2]. NADEP JAX will be expected to repair all assigned F404 engines and modules without a corresponding increase in engine repair personnel and facilities.

The NADEP JAX engine production supervisor indicated his facility is not at 100% capacity utilization and will be capable of accomplishing all assigned engine and module overhaul/repairs without increasing the number of shifts currently employed repairing F404 engines/modules.

This thesis will investigate the effects that the consolidation will have on NADEP JAX's ability to overhaul/repair engines and modules. The turn-around-time (TAT) and the number of engines/modules undergoing overhaul/repair at NADEP JAX will be studied to see if the consolidation will cause an increase or decrease in TAT and work-in-process (WIP) while keeping the production resources constant.

The problem will be studied using queueing theory and simulation. It will start by investigating NADEP JAX production prior to the consolidation effort, followed by an investigation of the effect of combining NADEP NORIS engine and module repair assignments with NADEP JAX engine/modules

---

[2] Engine/module overhaul/repair assignment - Engines and modules beyond the capability of the Aircraft Intermediate Maintenance Department (AIMD), are assigned monthly by NAVAIR to the NADEPs for repair. Assignment is based on current engine/module production and man hours available.

repair assignments. The focus will be on the transient behavior of the TAT, WIP and capacity utilization at NADEP JAX as a result of the consolidation.

B. HISTORY

In February 1989, President Bush directed Secretary of Defense (SECDEF) Cheney to develop a plan to improve the defense procurement process and management of the Pentagon and fully implement recommendations of the Packard Commission.[3]

In June 1989, as a result of the President's direction, SECDEF conducted a Defense Management Review (DMR) and forwarded a plan to the President that would:

- Implement fully the recommendations of the Packard Commission,
- Improve substantially the performance of the defense acquisition system; and
- Manage more effectively the DoD and defense resources.

In October 1989, as part of the DMR initiatives, Defense Management Report Decision (DMRD) 908 was published. According to DMRD 908 the DoD would consolidate the Army, Navy and Air Force aeronautical depot maintenance into a single

---

[3] The Packard Commission - The commission made clear that Americans think inefficiency in DoD spending to be a problem of major proportions. In brief, the Packard Commission concluded that the defense acquisition process was not being operated and managed effectively, and that this was having a disastrous effect on the cost and efficiency of the DoD acquisition process.

defense-wide entity. The report suggested that the management of DoD organic industrial resources within the Department of Defense might be merged efficiently and effectively.

DMRD 908 (Department of Defense, 1989) recommended that:

> Since the Air Force has a majority of aeronautical depot maintenance, they would be the logical choice as manager of the consolidated function. All resources associated with the performance of organic aeronautical depot level maintenance should be placed under this manager. A single manager should streamline the management of DoD organic industrial resources. Each military department would still be responsible for determining its depot maintenance requirements and budgeting for depot maintenance support.

DMRD 908 concluded that the recommended consolidation:

> "...should result in the closure of two of twelve organic aeronautical depots."

On 9 November 1989, a team consisting of the Office of the Secretary of Defense (OSD) (Production and Logistics), the Director of the Defense Logistics Agency (DLA), and Service representatives at the flag level was chartered by the Deputy Secretary of Defense (DEPSECDEF) to review DMRD 908 and to develop a recommended implementation plan. Special consideration was to be given to reduce DoD cost while preserving or enhancing operational support. The team presented DEPSECDEF with the following options:

1. Option 1 - Approve and implement DMRD 908 as written. Depot activity would be reduced by closing two of twelve aeronautical depots. DMR cost savings would be achieved by reducing the overall level of operations and maintenance funds provided to the operating forces, and by directing the services to make organizational changes, consolidate workload, and close depots. Management improvements would be achieved by consolidation of aeronautical maintenance under the Air Force.

2. Option 2 - Workload consolidation and increased interservicing. This option consisted of two alternatives: Option 2A - Internal Streamlining, and Option 2B - Internal Streamlining plus selected base closure. Under the Internal Streamlining alternative (Option 2A), the Navy would retain all six naval aviation depots, but would improve the cost effectiveness of depot maintenance support through "downsized" operations. A key element of this option was to increase depot maintenance interservicing of selected items. Option 2B includes all the above plus selected base closures to be made on the basis of further analysis.

3. Option 3 - Management Improvements. This option consisted of three alternatives: Option 3A - a DoD Corporate Board, Option 3B - a Corporate Board under the Joint Logistics Commander (JLC), and Option 3C - creation of a Defense Depot Maintenance Council (DDMC). The Option 3 alternatives were not accompanied by any direct cost savings, however it was anticipated that a high level management organization dedicated to improved depot level weapon system support would understand and be able to generate executable cost savings initiatives.

On 30 June 1990, following a review of the flag team's recommendations, DEPSECDEF Atwood (1990, 1) concluded that

> ...substantial opportunities exist to increase the efficiency and reduce the cost of the Department's depot maintenance operations, while ensuring that they continue to conduct effectively their crucial maintenance mission.

Atwood decided to hold the original DMRD 908 in abeyance. He directed the Secretaries of the Military Departments to take specific actions designed to achieve the objectives of the DMRD without implementing the "single manager" concept. In the area of aviation depot level maintenance, the Secretary of the Navy was directed by Atwood (1990, 1-2) to ensure that:

1. the naval aviation depot maintenance structure is streamlined so as to establish one aviation depot

maintenance hub[4] on the east coast of the United States and one on the west coast;

2. all non-hub aviation depot maintenance facilities are reduced in size and perform technology-specific maintenance, or are closed, as appropriate;

3. the workload of all naval aviation depot maintenance of a particular type of aircraft is performed at a single site, to reduce the number of product lines at a given depot;

4. engine depot maintenance is performed at no more than three depots; and

5. other maintenance workloads of the Department of the Navy are consolidated as appropriate.

Atwood (1990, 2-3) further directed that all the Service Secretaries were to:

1. Increase at least 10% over the next five years the amount of depot maintenance work of one military department that is performed by a depot of another military department, in the interests of efficiency;

2. Increase significantly the amount of depot maintenance work that is awarded competitively by the Military Departments, in the interests of efficiency; and

3. As soon as possible, and not later than the close of fiscal year 1993, achieve 100% depot capacity utilization defined and measured for this purpose on the basis of forty operating hours per week.

---

[4] Naval Depot Hubs - The depot hubs are major industrial support centers. The hub complexes are located at Naval Air Station Norfolk, Virginia and Naval Air Station North Island, California. They provide engineering, logistic, and maintenance support to the operating fleet. The hub consists of a Business Operating Center (BOC) which contains employees performing consolidated corporate business overhead functions, and a Depot Production Center (DPC) which provides technology and commodity focused manufacturing, rework and overhaul services in support of assigned weapon systems.

Finally, Atwood (1990, 3) directed the Service Secretaries to:

> submit to the Assistant Secretary of Defense for Production and Logistics by October 1, 1991 a plan for financial management, inventory control and other information needs for depot maintenance activities that maximizes the exchange of information among depots within the DoD, without regard to the military department of which they are a part, and that minimizes the number of unique information systems needed.

On 17 September 1990, Under Secretary of the Navy Howard was briefed by the Commander of the Naval Air Systems Command (NAVAIR) regarding the naval aviation depot corporate response to DEPSECDEF Atwood's 30 June tasking. According to CDR Heilman (1991a), following this briefing Howard asked that a detailed NAVAIR plan for achieving depot economies and efficiencies be presented to him not later than 30 November 1990.

On 28 September 1990, the Under Secretaries of the Army, Navy, and Air Force sent a joint memorandum to the Assistant Secretary of Defense for Planning and Logistics (P&L) entitled "Strengthening Depot Maintenance Activities (1990)." This document forwarded the Joint Service plan to reduce depot maintenance costs by 2.2 billion dollars through increased interservicing, greater competition, and a higher level of capacity utilization. The plan described in this memorandum complements a previous joint savings target of 1.7 billion dollars in the areas of depot streamlining, single siting, and workload consolidation. The total joint savings for FY91-FY95 are expected to be 3.9 billion dollars.

In order to respond to Under Secretary of the Navy Howard's request for a detailed plan, NAVAIR convened a meeting of the Naval Aviation Depot Corporate Board. On 10 October 1990, the Corporate Board chartered a DMR Study Team composed of NADEP, NADOC, and Headquarters representatives. The Team was asked to prepare a new corporate business plan incorporating DEPSECDEF Atwood's 30 June guidance and specifically addressing the savings goals contained in DMRD 908.

The team studied 52 separate consolidation options to determine which combinations of workload reposturing and streamlining opportunities would yield the best cost reductions for Naval aviation depot support. On 29 November, the new Naval Aviation Depot Corporate Business Plan was approved by COMNAVAIRSYSCOM and forwarded, via the Chief of Naval Operations (OP-51), to the Under Secretary of the Navy. Under Secretary of the Navy Howard approved the plan and sent it to the Assistant Secretary of Defense (P&L) on 4 February 1991.

C. ENGINE OVERHAUL/REWORK

As part of the strategy to achieve substantial cost savings[5], NAVAIR, in association with the NADOC and the six major aviation depots[6], conducted an evaluation of alternatives for depot repair of engines. The alternatives centered on consolidating depot engine repair from five to three facilities. Examination of each depot was accomplished focusing on engine workload direct labor hours, engine workload as a percentage of total depot workload, engine cost percentage of total depot cost, and historical costs of labor, overhead and materials. Each NADEP was then compared with the other depots doing similar engine repair work. The engine program evaluation resulted in two alternatives being presented:

Option 1 - Shut down NADEP Norfolk and NADEP JAX, re-align NADEP Alameda and NADEP NORIS engine workload. Table I.1 shows where engines are being overhauled and repaired as of FY-90 and where the engines would be repaired after NADEP Norfolk and NADEP JAX engine repair facilities were shut down.

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[5] Substantial cost savings at the engine repair facilities was expected due to the fact that engine repair industrial capability generates the most expensive operating costs.

[6] Major depots include: NADEP Jacksonville, FL., NADEP North Island, CA., NADEP Alameda, CA., NADEP Norfolk, VA., NADEP Pensacola, FL., and NADEP Cherry Point, SC.

Option 2 - Shut down NADEP Norfolk and NADEP NORIS, re-align NADEP Alameda and NADEP JAX engine workload. Table I.2 shows where engines are being overhauled and repaired as of FY-90 and where the engines would be repaired after NADEP Norfolk and NADEP NORIS engine repair facilities were shut down.

TABLE I.1 ENGINE DEPOT ALIGNMENT PLAN, OPTION 1

CURRENT REPAIR ACTIVITY	ENGINE TYPE	SINGLE SITE REPAIR ACTIVITY
Norfolk/Alameda	T-56	Alameda
JAX/Alameda	J-52/TF-34	Alameda
JAX/North Island	F-404	North Island
Norfolk	TF-30/F-110	Air Force
JAX	TF-41	Air Force

TABLE I.2 ENGINE DEPOT ALIGNMENT PLAN, OPTION 2

CURRENT REPAIR ACTIVITY	ENGINE TYPE	SINGLE SITE REPAIR ACTIVITY
Alameda/JAX	J-52	JAX
Norfolk/Alameda	TF-34	Alameda
North Island/JAX	F-404	JAX
NORIS/Cherry Pt.	T-58/T-64	Cherry Pt.
JAX/Air Force	TF-41	Air Force
NORIS/Air Force	LM-2500	Air Force
Norfolk/Air Force	TF-30/F-110	Air Force

The results of the economic analysis of the two engine streamlining options were presented in the "Engine

Observations and Alternatives (1990)" prepared by NADOC's Planning, Analysis, and Evaluation Division.

The results of the this NADOC study were forwarded to the Defense Depot Management Council (DDMC), and used in the DDMC Corporate Business Plan (FY 91 - 95). The DDMC Corporate Business Plan, page 18, gives a synopsis of the Observations and Alternatives investigation;

> Engine consolidation from five to three Naval Aviation Depots will result in long-range savings and interservicing opportunities. The results of the engine consolidations do not create savings within the Six Year Defense Program (SYDP) when viewed in isolation. However, the gaining Depot Production Center (DPC) will be able to accomplish engine work at a price equal to or less than those presently planned at the losing DPC. Once the non-recurring relocation investments are made, long-range savings will accrue. Non-recurring cost to reduce engine facilities is forecast to be 11.5 million dollars. This expense offsets the aircraft single site[7] savings which would have been 41.3 million dollars if engine repair consolidations had been cost neutral. In addition, the equivalent square footage of the excess engine facilities will be closed to eliminate unused capacity or converted to other uses to reduce future military construction requirements.

The final decision for engine rework consolidation in the case of the F404 engine and modules was to consolidate all F404 work at NADEP JAX. This effort was originally scheduled to take place over the next two years to be completed by September 1993. The Navy plan, according to Heilman (1991a),

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[7] By 1992, NAVAIR will have single sited all aircraft programs (except A-6) to reduce the number of product lines managed at a given depot. Aircraft single siting will produce cost savings of 29 million dollars for FY 91 - 95.

is to accelerate this schedule and complete the consolidation by September 1992.

D. CAPACITY UTILIZATION

The DDMC Corporate Business Plan indicates that, in response to DEPSECDEF Atwood's 30 June 1990 memorandum, as part of DMRD 908 cost savings the services were to achieve 100 percent utilization of depot maintenance facility capacity (i.e., match engine repair workload with engine repair capacity). Increasing capacity utilization was not to interfere with the efficiency of the depots and the depots were to maintain the infrastructure necessary to meet peace time and contingency needs. The DDMC (Department of Defense, 1990, 57) stated:

> The services were directed by DEPSECDEF to achieve 100% peace time utilization of depot capacity at major depot maintenance facilities. Even with the need to improve capacity utilization, the Navy, along with the other services, found that achieving 100% utilization often is a costly approach due to excessive work-in-process and inventories. A less costly approach would be to match flow with demand, which allows for the greatest degree of cost effective utilization. This approach further recognized the need for reserve capacity, or that unutilized capacity retained for reasons of military necessity (surge and mobilization) and sound business practices.

Combining F404 engine and module repairs at NADEP JAX, the facility's capacitity utilization will increase as directed under the original DMRD 908. In accordance with DoD Instruction 4151.15H, "Depot Maintenance Production Shop Capacity Measurement Handbook" dated 28 July 1978, NADEP JAX capacity is measured under peacetime production which uses a single shift and the percentage of direct productive work accomplished in an eight hour shift. DoD Instruction 4151.15H (1978, Section B, 1) says engine and module production capacity is a function of the following:

> Engine and module production capacity covers areas with processing aviation engines in terms of overhaul, low time, complete repair, and major inspection. The work functions include uncanning, disassembly, cleaning, metals examination, examination and evaluation, parts reconditioning, sub-assembly, final assembly, test and preservation.

The engine production supervisor at NADEP JAX indicates his facility has the capacity to absorb the engine production requirements from NADEP NORIS. One of the major focuses of this thesis is to investigate the relationship between the increased workload and the capacity utilization of the NADEP JAX F404 engine repair facility.

E. THESIS OBJECTIVE

The objective of this thesis is to investigate the effects of consolidating aviation depot engine repair without increasing the production resources at NADEP JAX. Although the economic impacts have been investigated by the Navy, no study has been done on the effects the consolidation will have on NADEP production. This thesis will focus on the following issues:

1. What is the current TAT for F404 engines at the engine depots, and how will the TAT be affected after the consolidation?

2. If the TAT is affected by the consolidation effort, how will it affect the total number of engines and modules that can be assigned to NADEP JAX for repair?

3. The capacity utilization will increase at NADEP JAX after the consolidation. What percentage increase can be expected, and will there be any capacity available for surge or war time requirements?

4. Using Fiscal Year (FY) 1990 and 1991 data as base line years, measure the effects the consolidation would have on NADEP JAX production. Calculate NADEP JAX's TAT and capacity utilization based upon actual FY 90 and 91 data. Then, assume the consolidation has gone into effect and, using the same FY 90 and 91 data, calculate the effect the consolidation would have on TAT and capacity utilization.

5. Using engine and module requirements forecasted by NAVAIR for FY-92, calculate the effect the consolidation will have on TAT and capacity utilization.

Chapter II will provide background information on queueing theory and simulation. Chapter III will provide an analysis of the problem using queueing and simulation. Chapter IV will provide an analysis of the problem using the queueing and simulation models discussed in Chapter III. Chapter V will contain summary, conclusions, and recommendations.

II. BACKGROUND

This chapter will explain the procedures and techniques used to identify data used to determine if there is a significant difference in depot level engine turn-around-time (TAT) and capacity utilization caused by the consolidation of F404 engine and module repair at NADEP JAX. If there is a significant difference in TAT, the impact of this change must be measured.

Queueing theory will be used to analyze the effect the consolidation has on the TAT and capacity utilization. Using queueing models, NADEP JAX's waiting lines and capacity as a function of arrival and service rates of the engines and modules can be studied. Simulation is then applied to see the transient behavior of TAT and WIP at NADEP JAX after consolidation.

First, a general overview of queueing theory will be discussed followed by an explanation of simulation modeling and its advantages.

A. DESIGNING THE EXPERIMENT

Queueing theory studies waiting lines, or in this case, engine and module depot level TAT or total days in process. Queueing problems start with a sequence of items (such as engines and modules) arriving at a service facility. As the engines arrive and are inducted for repair, other engines arrive and wait in the "queue" until they get inducted.

In the case of NADEP JAX and NORIS two queues are scheduled to be consolidated into one queue without any increase in production capability. Simply stated, NADEP JAX will absorb all of NADEP NORIS F404 engine work but will not get NORIS production resources. Rothkoph and Rech (1987) state that it is a simple matter to compare the steady-state average wait for systems. Wolff (1988) shows that the average wait in the combined queue is less than that found in a two queue system if the same level of resources are maintained. This means if NADEP JAX absorbed all NADEP NORIS F404 engine work and all production capacity as well, the average TAT for an engine or module would be less than with two geographically separated engine depots. However, transportation time would increase.

Disadvantages may present themselves in the consolidation of the engine depots. NAVAIR will no longer have the choice to choose from two available NADEPs. For total engine overhaul requirements, NAVAIR will be limited to one available server, NADEP JAX.

If combining the queues will cause full capacity utilization at NADEP JAX, then NAVAIR may encounter difficulties seizing opportunities to expanding engine repair. at NADEP JAX. For example, if combining the queues results in 95 to 100 percent utilization of the engine depot repair channel, it may deprive management of the opportunity to expand production during times of crisis, for example Desert Storm.

The Navy must ensure it has the optimal number (i.e., match engine and module workload to engine repair capacity) of repair channels available at the engine depots to support the fleet.

According to Ebeling (1989) as components fail during an operation, we expect them to enter a queue for repair. The component can enter the repair channel immediately upon arrival at the service area or it must wait until the repair channel is empty. Each component arriving at NADEP JAX for repair, an engine or module in this case, enters the depot where there is a repair channel for engines and a repair channel for each type of module. The engine or module can be inducted for repair immediately upon arrival at the depot or will have to wait until the appropriate service channel is available.

B. HYPOTHESIS

The operating characteristics determined from the arrival and service time distributions will serve as input into the decision-making process about the hypothesis under study.

1. Hypothesis Statement

The following hypothesis was formulated:

Null Hypothesis (H_0): Change in frequency distribution of arrivals and service times, as a result of consolidation, has no measurable effect on the number of engines and modules being serviced, the TAT, and capacity utilization.

Alternative Hypothesis (H_1): Change in frequency distribution of arrivals and service times, as a result of consolidation, has a measurable effect on the number of engines and modules being serviced, the TAT, and capacity utilization.

2. Approach

The hypothesis will be tested to see if the null hypothesis will be rejected. The approach to test the null hypothesis is as follows:

1. Collect engine and module interarrival and service times for all depot level facilities involved. Since detailed data is not available the interarrival and service times will be estimated from known engine and module inductions per quarter and TAT.

2. Calculate arrival and service times and use these to calculate waiting time, number of engines and modules in the system, and capacity utilized prior to the consolidation effort using queueing theory.

3. Predict waiting time, number of engines and modules in the system, and capacity utilized after the consolidation has taken effect.

4. Compare changes in the numbers of engines and modules in the system, the length of time or TAT, and the change in capacity utilization.

5. Analyze the data and determine whether or not the null hypothesis should be rejected or not. In other words, determine whether the change in frequency distribution of arrivals and service times has a measurable effect on the number of engines and modules, the TAT, and depot capacity utilization.

C. QUEUEING THEORY

1. Queueing Models

Queueing theory involves two key random variables and their probability distributions: 1) distribution of interarrival times, and 2) distribution of service times. These key random variables are the basis for solving questions concerning the depot consolidation. From the key random variables we can explore NADEP JAX's F404 engine repair operation with respect to:

1. The number of entities (engines/modules) in the system: the number of engines being served (overhauled/repaired), as well as those entities waiting for service.

2. TAT: the interval between when an engine/module enters the system and when it leaves the system. This interval includes service time, logistics and administrative delay time.

3. The waiting time in the queue: the time between engines entering the system and the beginning of service.

The key random variables and performance measures are represented by the following symbols:

- λ - mean arrival rate; $1/\lambda$ - mean time between arrivals,
- μ - mean service rate; $1/\mu$ - mean service time,
- L - Expected number of entities in the system,
- L_q - Expected number of entities in the queue,
- W - Expected time in the system, including service time,
- W_q - Expected time in the queue.

The quantities L, L_q, W, and W_q, are functions of the operating characteristics λ and μ, and require some interpretation. The expected numbers and waiting times are quantities the system has attained once it has reached a steady state. If the depot, for instance, operates continuously and long enough, it enters a steady state condition and exhibits stable behavior.

2. Little's Flow Equation

To study the effect depot consolidation has on interarrival times or service times, and the change in TAT, a graphical means for displaying the dynamics of the consolidation lead the investigation to one of the most significant results in queuing theory, "Little's Flow Equation" (Little, 1961, 383). Little proved that in a steady state queueing process:

$$L = \lambda W \tag{1}$$

This result states that L, the expected number of entities in the system equals λ, the arrival rate, times W, the expected waiting time. Likewise, Little's equation can be applied to the queue itself:

$$L_q = \lambda W_q \tag{2}$$

It is also known that:

$$W = W_q + 1/\mu \tag{3}$$

Equations 1, 2, and 3 make it possible to compute the four quantities L, L_q, W, and W_q once any one of them is determined given λ and μ.

3. Classifying Queueing Models

According to Gould, Eppen, and Schmidt (1988), to facilitate communication among those working on queueing models, D. G. Kendall proposed a taxonomy based on the following notation:

$$A/B/s$$

where A = distribution of interarrival times
B = distribution of service times
s = number of service channels

Different letters are used to designate certain distributions. By placing these in the A or B position they indicate the arrival or the service distribution, respectively. The following conventions are in general use:

M = exponential distribution
D = deterministic number
G = any (a general) distribution of service times
GI = any (a general) distribution of interarrival times

Queueing theory equations and classifications provide the necessary tools to analyze the depot consolidation and the effects on engine and module production as it relates to the number being repaired or work in process and the time in the system undergoing repair/overhaul. The thesis hypothesis can be tested and the effect of consolidating the depot level repair of F404 engines can be analyzed with this basic understanding of queueing.

D. INFORMATION COLLECTION

To correctly identify the objective and define the system boundaries, information about the NADEP JAX engine repair system was gathered. Data collected to drive the model included interarrival times and TAT.

Interarrival time and TAT data for this thesis came from several sources. Interarrival time was computed from information received from the engine production supervisors at NADEP JAX and NORIS. These individuals provided the number of F404 engine and module inductions per quarter from the first quarter of FY-90 to the third quarter FY-91 at NADEP JAX and NORIS. Additionally, the total number of forecasted engine and module repair requirements per year were taken from the NAVAIR Aircraft Engine and Module Requirement Forecast for FY-89 through FY-93. Other than the number of engines arriving per quarter or forecasted for a given year, no other information concerning the frequency of arrivals or the mean time between arrivals was available.

The time to repair engines and modules was not available. Turn-around-time data, taken from historical NADOC Industrial Performance Summary Reports for FY-90, was used to estimate the repair time of the engine and modules.

1. Interarrival Data

For NADEP JAX, there is a lack of information regarding the interarrival times of engines and modules and, as previously mentioned, must be estimated from the number of engines and modules arriving over a given period. There seems to be no arrival pattern to the arrival of engines or modules at the depot. The arrival of engines and modules at NADEP JAX is assumed to be a Poisson process as no other information was available other than the number of engines inducted per month. A Poisson process, according to Ravindran, Phillips, and Solberg (1987, 291), is often used to model arrival of customers over a given time. Combining the Poisson distribution at NADEP JAX with the Poisson distribution at NADEP NORIS results in a new Poisson distribution. This property is referred to as the regenerative property of Poisson distribution (Wolfe, 1988). The tables in Appendix A detail the results of interarrival calculations.

2. TAT and Repair Time

TAT is composed of three characteristics. These characteristics are:

1. Service time - active maintenance time required to actually repair a component.

2. Logistics Delay Time (LDT) - maintenance downtime as a result of waiting for a spare part to become available, transit time from the user activity to the depot, waiting for the availability of an item of test equipment in order to perform maintenance, waiting transportation, waiting to use a facility required for maintenance, etc.

3. Administrative Delay Time (ADT) - downtime during which maintenance is delayed for reasons of an administrative nature: personnel assignment priority, labor strike, organizational constraint, and so on.

Expressed mathematically TAT is computed as:

$$TAT = 1/\mu + LDT + ADT$$

The TAT can be used to calculate expected repair time ($1/\mu$). This calculation will be explained in Chapter IV. The important aspect to discuss at this point is the type of distribution the TAT follows.

Little is known about the repair time at NADEP JAX. Repair time data is not directly available from the Industrial Performance Summary for Aviation Depots. The primary measure of effectiveness for NADEP JAX engine production is TAT and this figure is available from the NADEP Industrial Performance Summary.

The TAT can be less than 10 days or more than 60 days. Figure 2.1 depicts the F404 engine TAT frequency distribution for NADEP JAX for the period FY-90. The repair time must be estimated from a calculation based on the average of the observed TAT using queueing formulas. The tables in Appendix B detail the repair time calculations based on TAT.

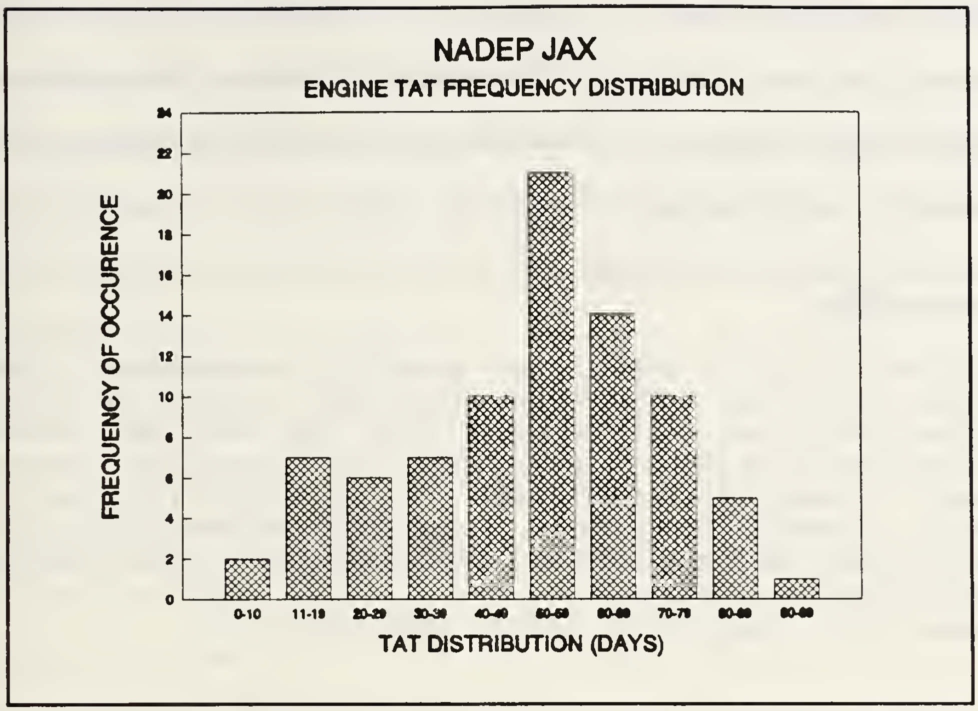

Figure 2.1 NADEP JAX FY-90 Engine TAT Frequency Distribution

If actual interarrival times and repair times were available the distributions of these random variables could be more accurately determined. According to Law and Kelton (1991, 325),

> In order to carry out a simulation using random inputs such as interarrival times or demand size, we have to specify their probability distribution.

Law and Kelton (1991, 325-326) also state,

> Almost all real systems contain one or more sources of randomness. It is generally necessary to represent each source of system randomness by a probability distribution (rather than just its mean) in the simulation model.

The relative frequency of the values or intervals is plotted and a frequency distribution can be determined. Selecting the possible distribution becomes a matter of judgement and experience. There are statistical tests called goodness of fit tests which can be done to determine the frequency distribution if the actual interarrival and repair time data is available.

E. SIMULATION

Simulation is a useful and powerful management science technique for use in the analysis of complex queueing problems. Computer simulation is an effective tool for analyzing different aspects of complicated stochastic systems. The reason why simulation models are used are:

1. Queueing models require a lot of strong assumptions.
2. Queueing models may be applicable to a certain family of systems which may not describe the NADEP JAX operation.
3. If the operation of a system is simple enough it may be possible to use queueing models to obtain exact information quickly. However, according to Law and Kelton (1991), most real world systems are too complex to be solved in this manner, and the system's model must be studied by simulation.

Simulation is used in this thesis to study the transient behavior of NADEP JAX's F404 engine operation when the NADEP engine consolidation goes into effect. Aspects of the consolidation to be studied are the affect on capacity utilization, TAT, and total work-in-process. The uncertainty in engine and module repair time at NADEP JAX make simulation useful.

Computer simulation software provides a way to conduct experiments through the use of logical and mathematical relationships to describe the behavior and structure of real world systems. As a tool in queueing analysis, simulation means imitating a waiting line and service line by generating random variates.

In a queueing simulation, the first and most important aspect of using computer simulation for decision making is to identify the problem in detail. According to Emmons, Flowers, Khot, and Mathur (1989), the basic requirements needing identification are:

1. The input population - who is the customer and what is the size of the customer population?

2. The process of arrivals - how do arrivals occur over a period of time?

3. The waiting line - does the waiting line queue have infinite capacity?

4. The service discipline - in what order to customers get served?

5. The number of servers - how many identical servers are there?

6. The distribution of service time - does the service time vary over a period of time?

Once the basic queueing problem questions have been formulated, the next question to ask is, "Can a simulation model provide a realistic picture of the behavior and structure of the real world system?" The model requires validation. According to Sargent (1988) model validation is frequently defined as ensuring that the computer simulation program and its implementation is correct. Sargent also indicates it is usually too costly and time consuming to determine that a model is absolutely valid over the complete domain of its intended application. Sargent states (1988, 33):

> Model validation is one of the most critical issues faced by the simulationist. Unfortunately, there is no set of specific tests that can be easily applied to determine the validity of the model. Furthermore, no algorithm exists to determine what techniques or procedures to use. Every new simulation project presents a new and unique challenge.

According to Sargent, several types of validation techniques can be used to verify the simulation model. If historical data exist, this data is used to build the model and then it is used to test if the model behavior follows the actual data. Asking people knowledgeable about the system whether the model and its behavior is accurately portraying the real operational environment is another reasonable way to check the validity of the simulation.

The internal validity of the model means to check the variability of the simulation model by running several replications of the model and determine the amount of internal stochastic variability in the model. In other words, the model should provide similar results after every replication it performs. According to Sargent, high variability may cause the model to be questionable, and the appropriateness of the system being investigated.

In this thesis the simulation will be validated by programming the model using the estimated interarrival and repair times from Appendices A and B. The simulation will be run and the TAT and work-in-process data will be recorded. The recorded results from the simulation will be compared to NADEP JAX FY-90 historical data to see if the model provides similar TAT and work-in-process data.

Computer simulations can randomly generate numbers, run the simulation again and again, and record the large amounts of simulation data for use in statistical analysis. Using simulation will permit a study of the effects of the NADEP consolidation. Once the appropriate model is designed and verified, many replications can be run for different operating alternatives, and statistics produced and analyzed to help in the decision process about those alternatives.

Simulation analysis can overcome the pitfalls associated with the basic queueing formulas, but the simulation can experience problems also. For instance, the simulation analyst needs a statistical background to analyze the production flow being simulated. According to Gould, Eppen, and Schmidt (1988), in a complex scenario no one may understand the interactions and the relationships well enough to build a simulation model that works effectively. In order to arrive at valid conclusions one must design appropriate experiments and analyze the resulting data. This often involves formal statistical methods and a high degree of technical expertise.

F. RESULTS FROM THE QUEUEING MODEL AND SIMULATION MODEL

A benefit of queueing theory and simulation is studying how waiting queues are affected by different arrival and service time distributions. This NADEP engine consolidation experiment will look at changing the interarrival time of engines and modules at NADEP JAX while maintaining a constant level of resources. Using TAT as a target performance measure that will be kept constant, interarrival times of engines and modules will be changed to reflect the increased number of engines and modules at NADEP JAX as a result of the consolidation. Utilizing the queueing model, changes in the service time required to maintain target TAT, if interarrival time increases, can be investigated. The change in capacity utilization and work-in-process as a result of increased interarrival times can also be examined.

If the mean service time is equal to or greater than the mean interarrival time the consequence is waiting queues that grow indefinitely. Simulation will be used to study this phenomenon which will be referred to as transient behavior. Transient behavior cannot be studied by simple queueing models. The transient behavior will be reflected in the change in TAT, work-in-process, and capacity utilization as NADEP JAX goes from a steady state operation to an unstable operation as a result of the consolidation. The transient behavior can be recorded and be plotted on graphs to give a visual display of the effects of consolidating NADEP JAX's engine operation.

DEPSECDEF Atwood (1990), tasked DoD depot organizations to increase capacity utilization to 100 percent at the depots. The simulation will permit an analysis of the capacity utilization under different alternatives.

As the Navy will be procuring more and more F404 engines and modules, can NADEP JAX be expected to repair engines and modules in sufficient quantities to meet fleet needs? The queueing model and simulation will provide insight into the effect on TAT and capacity utilization before and after the F404 engine depot level repair consolidation takes effect at NADEP JAX.

III. MODEL DESIGN

The study of the behavioral characteristics of the NADEP consolidation will, using queueing models, help us understand the effect different interarrival rates will have on repair time, given a target turn-around-time. Following the queueing model analysis, simulation models will be used to study the transient behavior of NADEP JAX production as a result of the consolidation. These models are studied in order to provide information on TAT and WIP of F404 engines and modules that can be used in the decision making process regarding how NAVAIR and NADOC will schedule engine repair at the depot.

The models will help us examine characteristics considered useful for fleet readiness decisions. These characteristics are the distribution of arrivals and repair time, expected values and variances of the queue length, waiting time, number in the system, and the service time, and capacity utilization. NAVAIR and NADOC can schedule engine and module repair at NADEP JAX using these characteristics that will help the production operation run at its optimal level (i.e., matching engine repair capacity to engine workload.

A. ASSUMPTIONS

Some knowledge of the NADEP production operation is essential for understanding this research. The following information is provided to help understand how the engine and module repair process at NADEP JAX works.

Engines or modules arriving at the NADEP are inducted for service in the order of their arrival. The number of engines and modules that arrive during a fixed period of time follow a Poisson distribution. As mentioned in Chapter II, the arrival of engines and modules at NADEP JAX is assumed to be governed by a Poisson process as no information was available, other than the number of engines inducted per month.

The service time for engines and modules at NADEP JAX is not available. The service time is calculated, from the total time in process at the depot (TAT) and the interarrival time, using the M/M/1 queueing model. The service time calculation will be explained later in the model design.

From discussions with the Engine Production supervisor at NADEP JAX and NAVAIR Code 431A, we will assume that available workload man-years will remain constant and will not increase at NADEP JAX when the F404 engine/module repair consolidation is complete. This assumption presumes that the number of shifts worked will remain constant (at a peacetime level) and that NADEP JAX currently has a single repair channel (or work shift) for each engine or module.

The available workload man-years remaining constant is based on the following knowledge: 1) the NADEP JAX Engine Production Supervisor stated his current F404 production is not 100% utilized; 2) NAVAIRSYSCOM Code 431A stated the NADEPs will be facing man-year reductions to meet DMRD 908 money saving goals thus reducing the opportunity to hire personnel; and 3) the current decreasing NADEP JAX operating budget limits the opportunity to hire more personnel. An increase in available technicians to repair F404 engines and modules is not expected.

Longer transportation times can be expected when moving engines and modules to or from the West Coast and can affect TAT. However, the study of how long transportation times will affect TAT is not a topic investigated in this thesis.

B. DATA

The data for this study was derived from Fiscal Year 1990. The data was compiled from several sources. These sources and the information gleaned from each include:

1. Industrial Performance Summary for Naval Aviation Depot Facilities, Annual FY 1990: Number of engines/modules completed and days in process. Days in process is assumed to be total time in the system or W.

2. NADEP Engine production supervisors: Provided the number of F404 engines/modules inducted at NADEP JAX and NORIS from October 1989 through June 1991.

3. NAVAIRSYSCOM Aircraft Engine/Module/Power Section/Gearbox Repair Requirement Forecast: FY-89 through 1993: provided engine/module repair requirements for future years. The future year requirements were used in the queueing models to estimate TAT time in future years.

The engine and module repair forecast for FY-92 delineates repairs/overhauls to be assigned to NADEP JAX and NORIS. The author assumes NAVAIR will continue to require the same number of engine/module repairs and overhauls in the future regardless of whether the repairs/overhauls are done by two activities or one consolidated activity. The author assumes the combined engine and module forecast requirements would be assigned to NADEP JAX.

C. QUEUEING MODEL (Basic Model)

Little's flow equations that were discussed in Chapter II, help establish the basic M/M/1 queueing model for this paper. First, the queueing model will be discussed, then the equations will be defined.

1. Model Definition

The M/M/1 queueing model is used to provide information on engine and module the repair time at NADEP JAX. If an engine is received by NADEP JAX for repair, only one repair channel is available. Like-wise, if a module is received only one channel is available for each type module.

2. Queueing Model Formulas

The following formulas use λ and μ to calculate the values for L, L_q, W, and W_q for the M/M/1 model.

Expected number in the system	L	$L_q+\frac{\lambda}{\mu}$
Expected number in the queue	L_q	$\frac{\lambda^2}{\mu(\mu-\lambda)}$

Expected waiting time in the repair queue	W	$W_q+\frac{1}{\mu}$
Expected time in the repair system	W_q	$\frac{L_q}{\lambda}$

3. Basic Model Data Description

As previously stated, the interarrival and repair time data used for this thesis is based on FY-90 historical NADEP JAX information.

a. Interarrival Time

The first data element estimated was the mean interarrival time for engines and modules. Engines and modules are assigned to a depot for repair on a monthly basis by NAVAIR, ASO, and NADOC. Based on data received from the engine production supervisors at NADEP JAX and NORIS, the mean interarrival times were calculated for the F404 engine and modules at each depot. Appendix A details the mean interarrival time calculations of engines and modules.

b. Repair Time

The mean arrival rate λ and the TAT were used to estimate the mean repair rate μ or the mean repair time $1/\mu$. Expected time in the system (W) or TAT for engines and each type module was calculated by using data from the NADOC Industrial Performance Summary for Naval Aviation Depot Facilities. Mean repair time was computed using the equation for expected time in the system (W):

$$W=\frac{1}{\lambda-\mu} \Rightarrow \lambda-\mu=\frac{1}{W} \therefore \mu=\lambda+\frac{1}{W}$$

For *W*, this latter equation uses average engine/module total days in process value. This value is obtained from the NADOC data. Appendix B details the results of this calculation.

D. SIMULATION MODEL

This thesis used SIMAN (Pegden, Shannon, and Sadowski, 1990) simulation language. SIMAN is designed around a logical modeling framework in which the simulation program is segmented into a "model" frame and an "experimental" frame. The model frame describes the physical elements of the system (engine and module failures, engine and module repairs, engine and module overhaul/repair flow, etc.) and their logical interrelationships. The experimental frame specifies the experimental conditions under which the model is to run, including elements such as initial engine and module availability, type of statistics gathered, and length of the simulation. Because experimental conditions are specified external to the model description, they are easily changed without modifying the basic model definition.

Once the model and experiment have been defined, they are linked and executed by SIMAN. As the simulation is executed, SIMAN automatically saves the system responses that the experiment indicates should be saved.

1. Model Frame

The basic structure of a SIMAN program model frame has the following elements:

- CREATE arrivals
- QUEUE to await service
- SEIZE the server when available
- DELAY by the service time
- RELEASE the server
- TALLY the time in system and depart

* Note: The Capitalized words are command words peculiar to SIMAN.

With these commands, the production flow of a complex production system can be simulated and analyzed.

The depot level repair simulation is designed to simulate the production activity at NADEP JAX over a 3 year period using the interarrival and service time data presented in Appendices A and B. The model is first run for 365 days with NADEP JAX operating at production level experienced in FY-90 and 91. The first 365 days allow for a warm-up period. After the warm-up period the program begins to collect statistics and the simulation runs for another 365 days. This information will be used as a comparison against the effects of the consolidation.

After 730 days, the model creates more depot engine and module repair work at NADEP JAX. This simulates the closing of the NADEP NORIS engine repair operation. The simulation was designed in this manner to analyze the transient behavior of NADEP JAX's engine repair operation as the consolidation takes effect.

The logic of the simulation model is as follows. First faulty engines and modules arrive at the depot for repair. When the simulation program creates an engine or module for repair and it is inducted, the simulation repair clock starts accumulating the time it takes to return the component to service.

Once the engine or module is created, the simulation delays the repair of the component from 40 to 50 days to account for the administrative and logistic delay time. The simulation delays the start of an engine or module repair by a delay statement inserted in the program. The 40 to 50 day delay time is based on conversations with the NADEP JAX engine supervisor and his knowledge of engine shipping and handling. Once the engine or module arrives at the depot, the simulation will either induct the component for repair or it will wait in the queue until the service channel is available. As previously discussed, engines and modules are inducted on a first come first serve basis.

In this simulation, the engine and each type of module have an assigned service channel. The time the service channel is occupied is recorded by the simulation program to estimate the utilization of the service channel.

Once the engine or module is repaired, the service channel is released so that another component can be inducted for repair. The engine or module that was repaired is assumed to be returned back into the supply system.

At the end of the simulation, the following data are collected. First, the total number of engines and modules repaired in each service channel is recorded. Next, the total time a component was in the service channel undergoing repair is recorded. Finally, the total time the service channel is either idle or in use is recorded so capacity utilization can be calculated.

2. Experimental Frame

The experimental frame of the simulation provides the length of time the simulation will run, the number of replications, and the characteristics of the resources and queues.

a. TALLIES Element

This element, along with the DSTAT element, are the most important parts of the experiment component. The TALLIES element provides descriptive information about the model's tally records that are used to determine the total number of engines and modules repaired at the depot in a specified period.

b. DSTAT Element

The DSTAT element records time-persistent variables which include the number of engines/modules in the queue and the channel utilization. For example, the NR(EngChannel) statement tells SIMAN to keep statistics on engine repair channel utilization, and the NQ(EngChannelQ) statement tells SIMAN to track the number of engines in the queue.

c. Replication

The simulation can be run for any length of time. For our analysis simulations were run for three years (1095 days). The length of time the models run simulate three different periods:

1. Replication for the FY-90 and 91 simulation: the simulation runs for 1095 days simulating the operation of NADEP JAX from the first quarter FY-90 to the third quarter Fy-91. As previously discussed the first 365 days are used as a warm-up period to let the simulation program reach a steady state. The second 365 days simulate NADEP JAX engine/module production prior to the consolidation taking place and is used for comparison against the effects of the consolidation. The final 365 days simulates the effect of consolidating NADEP JAX and NORIS engine/module repair operation. On day 730, the consolidation takes effect, and the number of engines arriving increases by an amount equal to the interarrival rate at NADEP NORIS.

2. For a surge or mobilization scenario, engine/module arrival data for the Desert Storm period was used. Like the FY-90 and 91 simulation, this simulation runs for 365 days as a warm-up period. The second 365 days, NADEP JAX receives engines without the consolidation in effect. At the 730 day mark, the number of engines arriving increases by an amount equal to the interarrival rate at NADEP NORIS to simulate the consolidation.

3. The FY-92 engine and module repair simulation is programmed to simulate what NADEP JAX repair operation may look like based on forecasted engine and module repair requirements. Like the other simulations, this simulation runs for 365 days to allow for a warm-up period. The second 365 days simulates NADEP JAX operating prior to the consolidation and for the final 365 days, the simulation runs with the consolidation having gone into effect.

The three replications listed above are used to study the NADEP consolidation under varying periods and component arrival rates. The resources available (i.e., repair technicians, support equipment, spare parts, etc.) for repair are assumed to remain constant and were simulated by keeping the same mean repair time for the engines and modules through all the simulations.

IV. ANALYSIS

Chapter III of this thesis has described the queueing models used with the operating characteristics of interarrival time and service times. It focused on how queueing theory and simulation can be used to measure the effect NADEP engine consolidation will have on TAT and capacity utilization.

This chapter discusses estimates of the TAT, capacity utilization, and number c_ engines in active repair (work-in-process or WIP). It contains the results from the queueing model and from the simulation model. Queueing equations were calculated using STORM, version 2.0 (Emmons, Flowers, Khot, and Mathur, 1989) software and the simulation program was written using SIMAN simulation language.

The focus of this analysis is to investigate whether combining the workload at NADEP JAX without increasing the production resources will cause longer TAT of F404 engines and modules, increase WIP, and if capacity utilization will be affected by the consolidation.

A. QUEUEING MODEL ANALYSIS

The queueing model used in this thesis to represent NADEP JAX is an M/M/1 queue. Numerical results from this model were obtained using STORM, a quantitative decision making software program. STORM calculated TAT, WIP, and capacity utilization for each of the following time periods: FY-90 and 91, Desert Shield/Storm; fourth quarter FY-90 to the third quarter FY-91, and FY-92. Each queueing model statistical calculation required the service time to be estimated based on a given interarrival time and TAT for the engine and the modules during the period being studied. From Appendices A and B the following interarrival and service times (Tables IV.1, IV.2 and IV.3) were used in the queueing model calculations and in the simulation model.

Table IV.1 NADEP JAX INTERARRIVAL TIMES ($1/\lambda$)

Nomen	FY 90/91 Comb.	Desert Storm
ENG	4.23 days	3.25 days
FAN	4.02 days	3.75 days
HPC	4.60 days	5.87 days
HPT	14.43 days	9.64 days
LPT	24.42 days	22.50 days

TABLE IV.2 NADEP NORIS INTERARRIVAL TIME ($1/\lambda$)

Nomen	FY 90/91 Comb.	Desert Storm
ENG	5.83 days	6.28 days
FAN	6.61 days	6.20 days
HPC	6.90 days	5.87 days
HPT	12.96 days	14.21 days
LPT	26.46 days	20.77 days

TABLE IV.3 NADEP JAX TURN-AROUND-TIME (TAT) AND REPAIR TIMES

Nomen	Average TAT	FY90 & 91 $1/\mu$	Desert Storm $1/\mu$	FY-92 Forecast $1/\mu$
ENG	52.4 days	3.92 days	3.06 days	5.70 days
FAN	50.0 days	3.72 days	3.48 days	5.19 days
HPC	50.6 days	4.22 days	5.26 days	2.21 days
HPT	51.3 days	11.26 days	8.12 days	5.52 days
LPT	46.0 days	15.95 days	15.12 days	5.71 days

The NADEP JAX Engine Production Supervisor (Harpster, 1991) indicated that a goal of the depot was to repair and overhaul engines to meet the target TAT. The average engine and module TAT were calculated from the Industrial Performance Summary, Annual FY 1990 data. The calculated average TAT for the F404 engine and module appear on the second column of Table IV.3. The TAT includes the actual engine or module repair time plus the logistic and administrative delay time.

The queueing model calculations show that in order to maintain a prescribed TAT given a specific arrival rate, the NADEP service time would need to decrease. The results will be discussed in the following order:

1. The first set of results will provide information regarding the F404 engine and module TAT, WIP, and NADEP JAX capacity utilization prior to the consolidation effort taking effect. Calculations were made for two separate time periods: FY-90 and 91, and Desert Storm.

2. The second set of results will provide information regarding the F404 engine and module TAT, WIP, and NADEP JAX capacity utilization after the consolidation. Calculations were made to simulate NADEP JAX's production efforts as if the consolidation had taken place for two

time periods: FY-90 and 91, and Desert Storm. It assumed the combined NADEP NORIS and JAX F404 engine and module repair requirements for periods FY-90 and 91, and Desert Storm had been placed upon NADEP JAX without an increase in production resources.

3. The final set of results will provide information for the period FY-92. The F404 engine and module repair requirement forecast was studied to estimate the TAT, WIP, and capacity utilization at NADEP JAX during FY-92.

1. NADEP JAX (FY-90 and 91)

The results of the calculations (Table IV.4) show that the repair time for an engine would had to have been decreased in order to maintain the TAT of 52.4 days if NADEP JAX had undergone consolidation during the FY-90 and 91 period. This requirement for decreased service time was also found in the analysis of the four modules under investigation. Appendix B details the results of the service time calculations. The repair times for the engine and modules before and after the consolidation effort are:

TABLE IV.4 NADEP JAX REQUIRED REPAIR TIME TO MEET THE TARGET TAT

Nomenclature	Repair Time Before Consolidation	Repair Time After Consolidation
Engine	3.92 days	2.34 days
FAN	3.72 days	2.41 days
HPC	4.22 days	2.62 days
HPT	11.26 days	6.08 days
LPT	15.95 days	9.96 days

Table IV.4 shows that capacity utilization of the engine and module service channels also increased when the number of arrivals increased. According to the STORM calculations, the F404 engine service channel repair time was 3.92 days and the capacity utilization was 92.6 percent before the consolidation of the depot engine operation. After the consolidation the engine service channel repair time was reduced to 2.34 days and capacity utilization increased to 95.5 percent. The NADEP JAX engine and module service channel capacity utilization increased as follows:

TABLE IV.5 NADEP JAX CAPACITY UTILIZATION COMPARISON TO MAINTAIN THE TARGET TAT

Nomenclature	Capacity Utilized before Consolidation	Capacity Utilized after Consolidation
Engine	92.6%	95.5%
FAN	92.6%	95.3%
HPC	91.7%	94.9%
HPT	78.0%	88.1%
LPT	48.9%	78.4%

The number of engines and modules in active repair increased after the number of arriving engines and modules increased. Table IV.6 shows that when the target TAT is met and the number of engines and modules arriving in the repair system increases, the total number of engines and modules in work increases.

TABLE IV.6 NADEP JAX WIP COMPARISON TO MAINTAIN THE TARGET TAT

Nomenclature	WIP Before Consolidation	WIP After Consolidation
Eng	13	21
FAN	13	20
HPC	11	19
HPT	4	7
LPT	1	4

2. NADEP JAX (Desert Storm)

For the Desert Storm surge scenario, the STORM calculations indicate similar queueing results. In this scenario the period studies the 4th quarter of 1990 through the 2nd quarter of 1991. Calculations reveal that by combining the repair workload of NADEP NORIS with that of NADEP JAX, at NADEP JAX, during Desert Storm, the expected service time would need to be decreased in order to maintain the specified turn-around-time as shown in Table IV.7.

TABLE IV.7 NADEP JAX REQUIRED REPAIR TIME COMPARISONS TO MEET THE TARGET TAT (DESERT STORM)

Nomenclature	Repair Time Before Consolidation	Repair Time After Consolidation
Engine	3.06 days	2.06 days
FAN	8.12 days	2.06 days
HPC	5.26 days	2.77 days
HPT	8.12 days	5.16 days
LPT	15.12 days	8.75 days

NADEP JAX's capacity utilization increased (Table IV.8) for both the engine and the modules when the repair requirements of both depots were combined at NADEP JAX.

TABLE IV.8 NADEP JAX CAPACITY UTILIZATION COMPARISON TO MAINTAIN THE TARGET TAT (DESERT STORM)

Nomenclature	Capacity Utilized Before Consolidation	Capacity Utilized After Consolidation
Engine	94.2%	96.3%
FAN	92.8%	95.8%
HPC	89.6%	94.5%
HPT	84.2%	89.9%
LPT	67.1%	81.0%

For this scenario, the number of engines and modules in active repair increased after the number of arriving engines and modules increased. Table IV.9 shows the WIP or expected number of engines and modules in the repair system after increasing the number of arrivals.

TABLE IV.9 NADEP JAX WIP TO MAINTAIN THE TARGET TAT (DESERT STORM)

Nomenclature	WIP Before Consolidation	WIP After Consolidation
Eng	16	26
FAN	13	23
HPC	5	17
HPT	5	9
LPT	2	4

3. NADEP JAX FY-92 FORECAST

The forecasted engine and module forecast repair requirements were examined to see what the repair time, capacity utilization, and WIP would be if the engines were inducted as shown in Table IV.10 and TAT targets were to be maintained as previously listed. The engine and module repair requirements are an estimate based on historical fleet needs and depot production capabilities. The repair requirement forecast is made by personnel at NAVAIR Code-410.

TABLE IV.10 FY-92 FORECAST ENGINE AND MODULE REQUIREMENTS AND INTERARRIVAL TIMES

Nomen	NORIS REPAIRS	JAX REPAIRS	NORIS $1/\lambda$	JAX $1/\lambda$
ENG	31	26	11.77 days	14.04 days
FAN	37	26	9.86 days	14.04 days
HPC	118	40	9.06 days	9.13 days
HPT	43	16	8.49 days	22.81 days
LPT	33	23	11.06 days	15.87 days

NADEP JAX repair time and capacity utilization calculations for FY-92 are based on the interarrival times listed in Table IV.10. In order to repair the forecasted number of F404 engines and modules in FY-92, and maintain the FY-90 average TAT, NADEP JAX service time and capacity utilization calculations resulted in the following estimates of required service times, capacity utilizations and WIP amount.

TABLE IV.11 NADEP JAX FY-92 FORECAST

Nomenclature	Repair Time	Capacity Utilized	WIP
Engine	5.70 days	89.0%	8
FAN	5.19 days	90.8%	8
HPC	2.21 days	95.7%	22
HPT	5.52 days	90.8%	10
LPT	5.71 days	87.6%	7

In all probability, more engines and modules are expected to be assigned to NADEP JAX for repair during FY-92 than the forecast indicates. As shown in Table IV.12, in FY-90 the number of engines inducted for repair was greater than the forecast requirement. The actual number of engines and modules repaired in FY-89 and the first three quarters of FY-91 also exceeded the forecasted number of required repairs.

TABLE IV.12 FY-90 FORECAST REPAIRS vs ACTUAL REPAIRS

Nomenclature	FY-90 Forecast Repairs	FY-90 Actual Repairs
Engine	109	169
FAN	213	132
HPC	295	134
HPT	43	39
LPT	50	25

The number of engines and modules inducted by the depot for repair in FY-92 may be greater than the forecast because of safety of flight requirements or, as in FY-90 and 91, because of a surge requirement. Operational requirements can cause more engine and module inductions because of increased flight hour activity.

B. SIMULATION ANALYSIS

The purpose of the simulation is to overcome the problems associated with the queueing formulas used to express the M/M/1 model. The M/M/1 model was used for simplicity and gave quick calculations of the service rate required to maintain the same TAT targets. The major problem is that the repair time must be recalculated when the number of arriving engines or modules increases. When the engines and modules arrive faster than the repair operation can fix them, then the queueing formulas reflect an unstable queueing pattern. It is analytically impossible for the queueing model to make calculations when $\lambda/\mu > 1$ (the case for the consolidation) and transient analysis is extremely difficult.

A SIMAN program was designed to simulate the consolidation at NADEP JAX and record the transient behavior of the production output. The focus of the simulation was to investigate the effect consolidating the engine repair operation will have on the number of engines and modules in work and the TAT during different scenarios.

Three simulation models were designed for different periods and scenarios: FY-90 and 91 peace time scenario; Desert Storm or mobilization scenario; and the FY-92 peace time forecast. Two elements were different in each simulation model, 1) the interarrival times for each scenario were set based on Appendix A data and, 2) the length of time the simulations ran was changed to simulate a specific time period. The service time remained constant throughout all the simulations.

Sensitivity analysis was conducted on the service time was conducted to arrive at a simulation model that accurately reflected the NADEP JAX repair operation. The model was validated by running the program using interarrival, logistic and administrative delay, and repair times that would provide TAT that closely approximated the target TAT previously listed.

The first model used a repair time that followed an exponential distribution. The TAT from that model was higher than the target values probably due to the high variance imparted by the distribution used.

The second model followed a normal distribution and used a repair time with the same mean as in the exponential model and a standard deviation equal to 20 percent of the mean. Using mean repair time with a standard deviation provided relatively smaller repair time variability but still yielded TAT higher than the target values.

The third model used a triangular repair time distribution to reduce the variability more than the normal distribution. The triangular distribution limited the length of time a repair could be accomplished by indicating a minimum, maximum, and average repair time value. The minimum and maximum repair time values were estimated by the author from data that was informally collected during his fifteen years of involvement in Navy aircraft maintenance.

The triangular distribution was chosen for the simulations used in this thesis. Results of this simulation model will be described in the following order:

1. A simulation of NADEP JAX F404 engine repair operation for the period FY-90 and 91.
2. A simulation of NADEP JAX F404 engine repair operation for the Desert Storm period.
3. A simulation of NADEP JAX F404 engine repair operation for FY-92.

1. NADEP JAX, FY-90 and 91 Simulation

Figure 4.1 shows a sample SIMAN output. It provides average, minimum, maximum, and final statistical values generated by the model. Figures 4.2 and 4.3 are graphs of the TAT and WIP plots for the F404 engine. After the warm-up period of 365 days, the plots indicate that the NADEP JAX engine repair operation TAT stabilized at approximately 54 to 55 days and engine WIP averaged less than five engines.

When NADEP NORIS repair requirements were placed upon NADEP JAX at the beginning of the third year (day 730), the TAT increased to over 80 days by the end of the third year. Engine WIP increased and, at the end of three years, WIP had increased from five to thirty engines.

All the F404 modules exhibited a similar transient pattern. When the depot module repair requirements from NADEP NORIS were combined with NADEP JAX, the TAT and WIP increased rapidly after the end of the second year. Appendix C, Figures C.1 through C.8, show the module TAT and WIP plots for the simulation time period FY-90 and 91. The average capacity utilization from day 365 through day 1095 of the simulation at NADEP JAX was:

- Engine: 93 percent
- FAN: 94 percent
- HPC: 87 percent
- HPT: 78 percent
- LPT: 77 percent

At the end of the simulation, the recorded capacity utilization shows that each service channel was at 100 percent utilization after 1095 days. The simulation results for this period indicate NADEP JAX engine operation is experiencing unstable behavior and the number of engines in work and the TAT will continue to increase. This unstable queueing behavior results when λ is greater than μ. The engines are arriving faster than they can be repaired.

Summary for Project: FY90_91 NADEP JAX

Replication ended at time : 1095.0
Statistics were cleared at time: 365.0
Statistics accumulated for time: 730.0

TALLY VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Observations
Time in Sys for Eng	84.729	.42436	47.179	171.58	189
Time in Sys for FAN	65.861	.24038	44 748	101.62	198
Time in Sys for HPC	78.735	.37980	46.447	160.40	159
Time in Sys for HPT	104.39	.46387	49.274	203.95	57
Time in Sys for LPT	82.785	.27835	52.680	131.70	39

DISCRETE-CHANGE VARIABLES

Identifier	Average	Variation	Minimum	Maximum	Final Value
Eng channel util	.92875	.27697	.00000	1.0000	1.0000
Avg Nr Engs in Chl	12.289	1.1561	.00000	43.000	40.000
ENG_WIP	13.218	1.0797	.00000	44.000	41.000
Fan channel util	.94215	.24778	.00000	1.0000	1.0000
Avg Nr FANs in Chl	5.2572	1.0409	.00000	20.000	20.000
FAN_WIP	6.1993	.89244	.00000	21.000	21.000
HPC channel util	.87483	.37826	.00000	1.0000	1.0000
Avg Nr HPCs in Chl	9.3045	1.2637	.00000	39.000	39.000
HPC_WIP	10.179	1.1652	.00000	40.000	40.000
HPT channel util	.78278	.52679	.00000	1.0000	1.0000
Avg Nr HPTs in Chl	6.0045	1.1729	.00000	21.000	20.000
HPT_WIP	6.7873	1.0663	.00000	22.000	21.000
LPT channel util	.77102	.54497	.00000	1.0000	1.0000
Avg Nr LPTs in Chl	1.6358	1.2852	.00000	7.0000	6.0000
LPT_WIP	2.4068	.96064	.00000	8.0000	7.0000

Figure 4.1 SAMPLE SIMAN OUTPUT FOR FY-90 and 91 MODEL

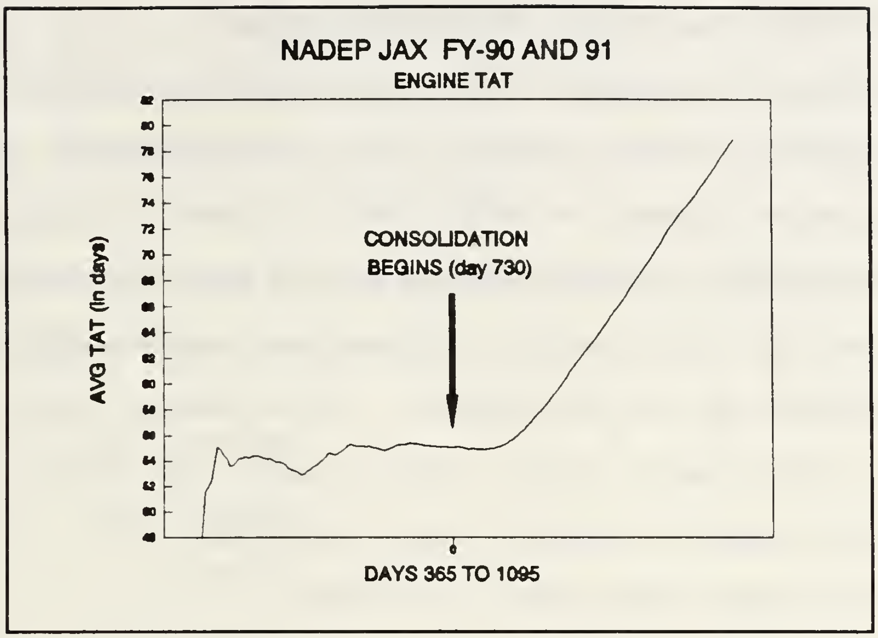

Figure 4.2 NADEP JAX F404 TAT FY-90 and 91

The Y axis (AVG TAT) of Figure 4.2, is computed from TAT generated in the simulation from day 365 to day 1095.

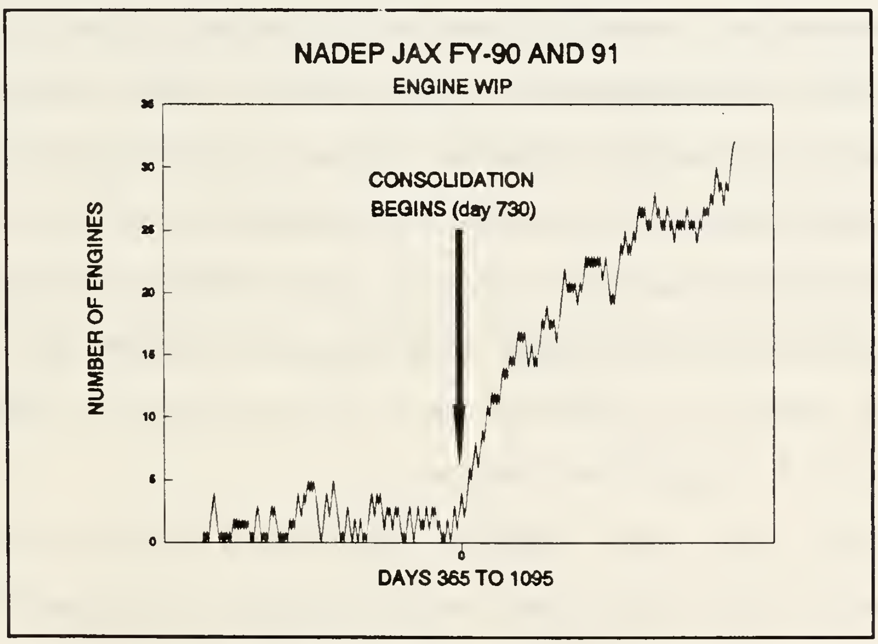

Figure 4.3 NADEP JAX F404 WIP FY-90 and 91

2. NADEP JAX, Desert Storm Simulation

Figures 4.4 and 4.5 are the graphs of the TAT and WIP plots for F404 engine repair that were obtained using an arrival process based on data from the Desert Storm period. After the initial 365 day warm-up period the TAT for an engine stabilized at approximately 120 days and engine WIP averaged approximately 20 to 40 engines. The Desert Storm warmup period values were much higher than the FY-90 and 91 simulation because engines were arriving more frequently (every 3.25 days vice every 4.23 days.

At the conclusion of the simulation and after consolidation, TAT was averaging more than 165 days and the WIP at day 1095 had risen to over 90 engines. A TAT increase of 45 days and an increase of 40 engines in work in process had occurred in the third year of the simulation.

The simulation for the Desert Storm time period resulted in transient behavior patterns similar to the FY-90 and 91 period. The engine interarrival times increased substantially during this period. The TAT and WIP plots for the engine indicate a rapid increase once the repair workload of NADEP NORIS is combined with the workload at NADEP JAX. Once again λ is greater than μ.

All the F404 modules exhibited similar transient patterns. When the depot module repair requirements were combined at NADEP JAX, the TAT and WIP increased rapidly at the end of the second year of the simulation and the consolidation begins. Appendix C, Figures C.9 through C.16, show the module TAT and WIP plots for the Desert Storm simulation.

Average capacity utilization from day 365 to day 1095 of the Desert Storm model was:

- Engine: 100 percent
- FAN: 100 percent
- HPC: 74 percent
- HPT: 100 percent
- LPT: 77 percent

At the end of the simulation, capacity utilization recorded by the simulation shows that the service channel was at 100 percent utilization after 1095 days. The low averages for the HPC and LPT are a result of the low utilization of the service channel prior to the consolidation. The simulation results for this period indicate that NADEP JAX engine operation is experiencing unstable behavior and the number of engines in active repair and the TAT will continue to increase.

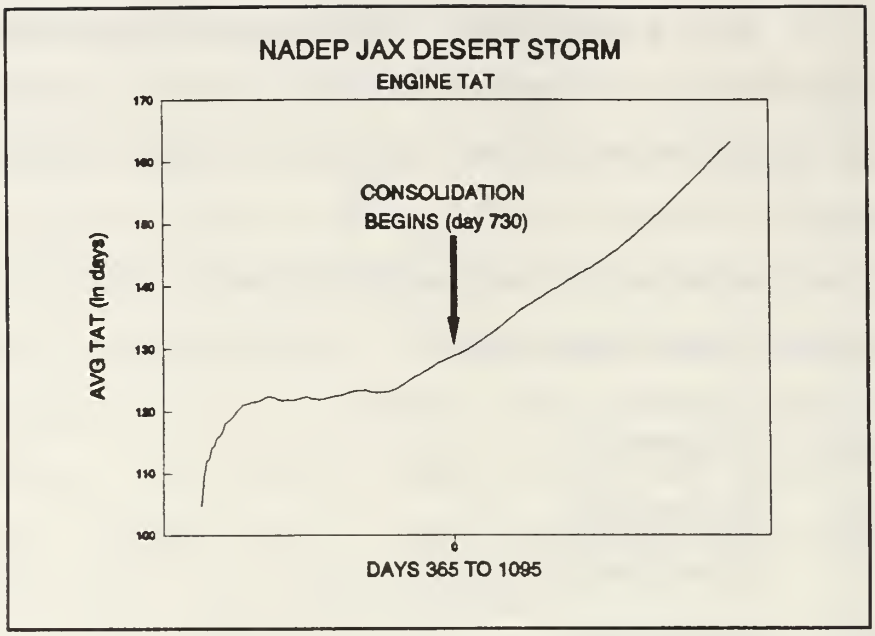

Figure 4.4 NADEP JAX F404 TAT Desert Storm

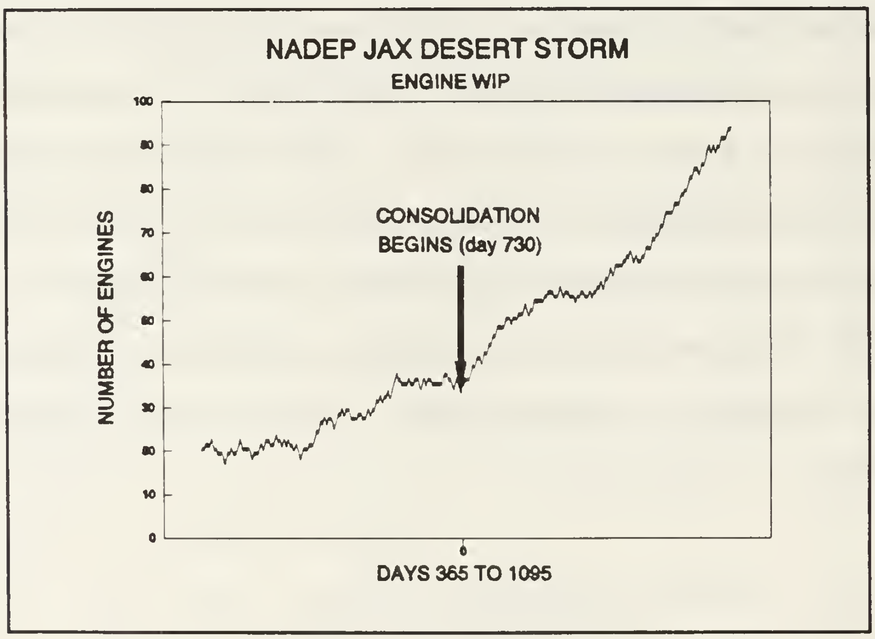

Figure 4.5 NADEP JAX F404 WIP Desert Storm

3. NADEP JAX, FY-92 Simulation

Figures 4.6 and 4.7 are the graphs of the TAT and WIP plots for F404 engine repair for the FY-92 forecast. The plots indicate that NADEP JAX engine operation can repair the FY-92 engine requirements with no significant increase in TAT or WIP. After the initial warm-up period, the TAT stabilized between 50 and 54 days and engine WIP averaged less than three engines.

At the conclusion of the simulation, TAT was averaging 54 days and exhibited stabilized behavior. The WIP at day 1095 had a slight increase and never exceeded five engines at any time.

The engine simulation results for FY-92 indicate a stable behavior pattern for NADEP JAX. Engines did not arrive as frequently as in the simulations using FY-90 and 91, and Desert Storm data. The TAT and WIP plots for the engine indicate no significant increase when the simulation starts combining the engine workload at NADEP JAX. The F404 FAN module exhibited a transient pattern similar to the engine. FAN repair indicated very stable queueing behavior.

However, the HPT, HPC, and LPT transient patterns indicate that TAT and WIP will continue to increase. As shown in Figures 4.8 and 4.9, the TAT and WIP for the HPC never stabilized after the initial warm-up period. The HPT and LPT

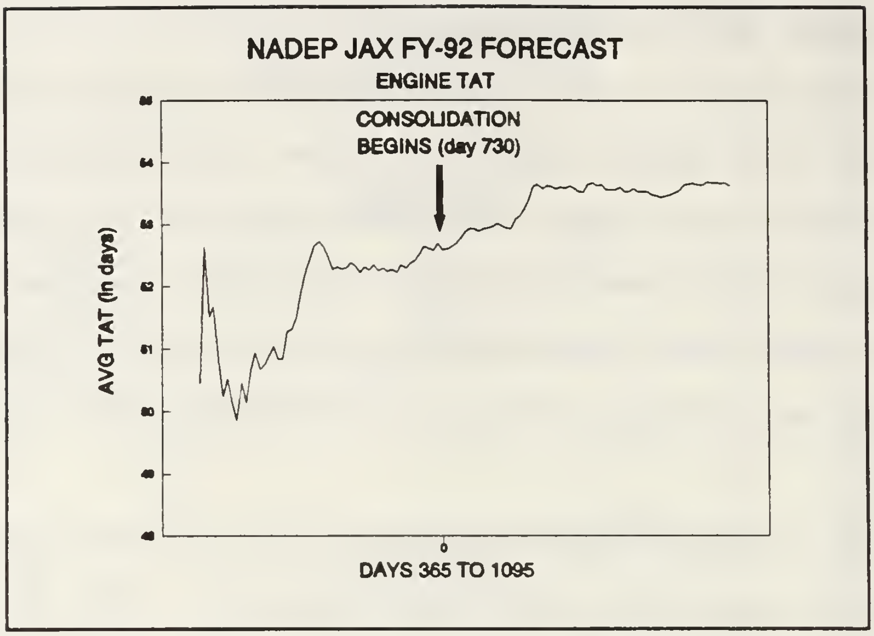

Figure 4.6 NADEP JAX F404 TAT FY-92 Forecast

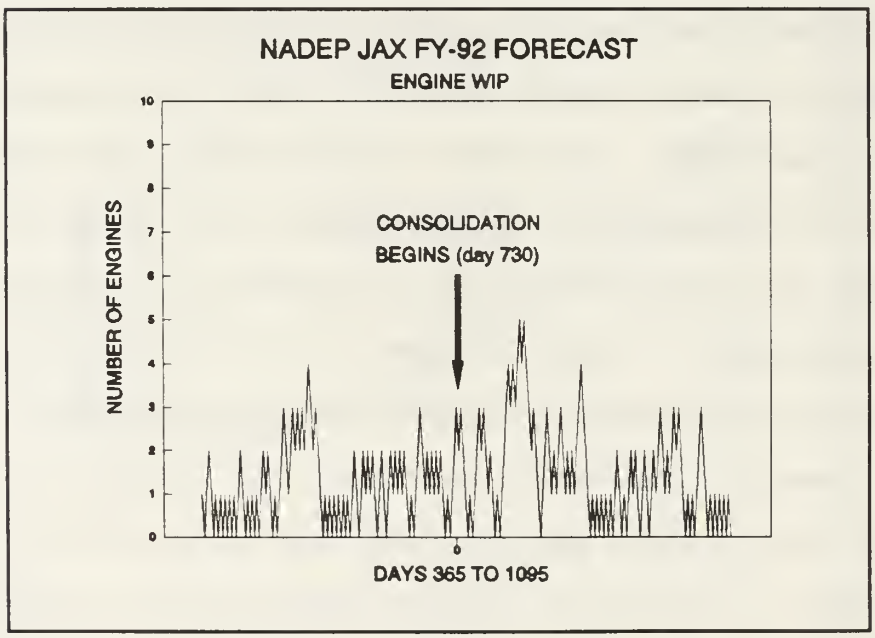

Figure 4.7 NADEP JAX F404 WIP FY-92 Forecast

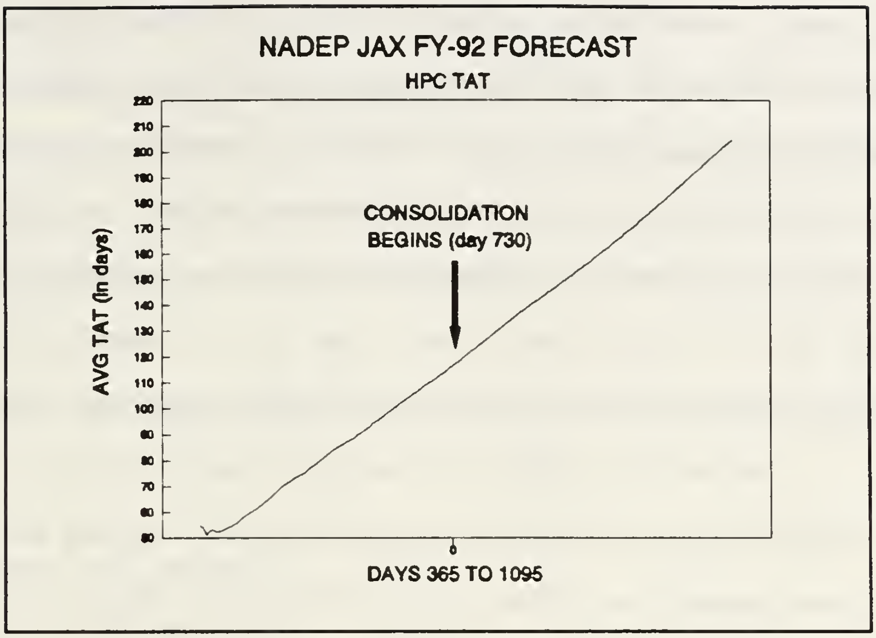

Figure 4.8 NADEP JAX HPC TAT FY-92 Forecast

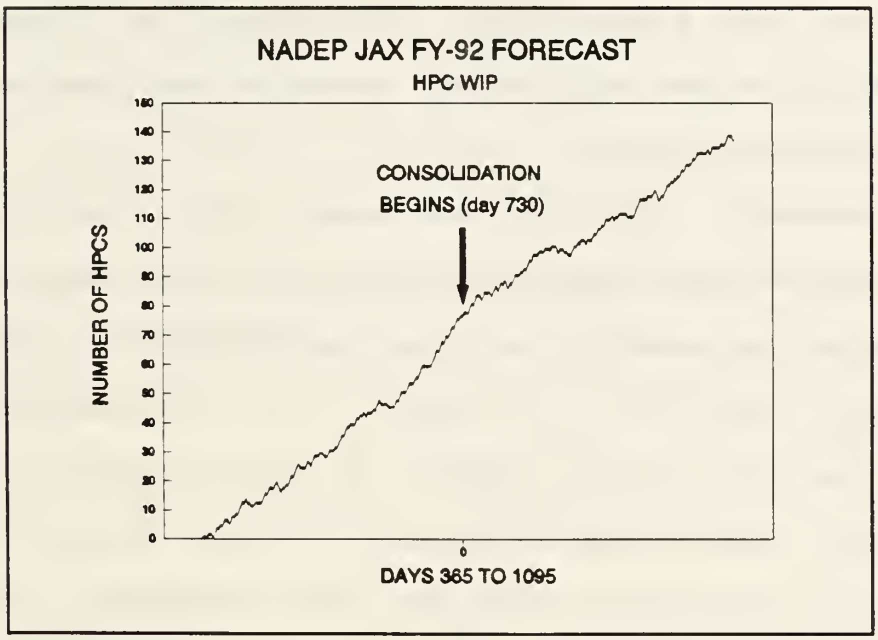

Figure 4.9 NADEP JAX HPC WIP FY-92 Forecast

TAT and WIP plots were similar to the HPC plots. The simulation indicates that there may be too many HPC, HPT, and LPT repairs scheduled for depot repair in FY-92. Appendix C, Figures C.17 through C.24, show the module TAT and WIP plots for the FY-92 simulation. Here the unstable queueing pattern exhibited by the HPC, HPT, and LPT is a result of these modules arriving faster than they can be repaired (λ greater than μ).

As previously stated, the forecasted engine and module repairs are based on data taken from the NAVAIR Aircraft Engine/Module/Power Section/Gearbox Repair Requirement Forecast: Fiscal Years 1989 through 1990. This document is used by NAVAIR and NADOC as a reference document to help prepare the yearly depot budget. The quantities forecasted in the document are anticipated removals and are used for planning purposes only.

However, as history has shown, the actual number of engines and modules requiring repair can be different from the forecasted requirement. As shown in Table IV.12, the number of engines inducted by the depots in FY-90 was significantly higher than the forecast number. On the other hand the number of modules repaired was much lower than the forecast levels.

The simulation runs that use forecasted engine and modules repair data indicate that NADEP JAX can handle the engine and FAN workload for FY-92 without TAT and WIP increasing. However, the HPC, HPT, and LPT workload may cause

NADEP JAX's TAT and WIP for these modules to increase significantly. If a workload similar to that experienced during the first quarter FY-90 through the third quarter FY-91 repeats in FY-92, NADEP JAX will not be able to meet the consolidated demand without experiencing an increase in TAT and WIP.

The average capacity utilization from day 365 to day 1095 of the FY-92 simulation for NADEP JAX were:

- Engine: 56 percent
- FAN: 59 percent
- HPC: 98 percent
- HPT: 96 percent
- LPT: 100 percent

The capacity utilization of the engine and module service channels indicate that, on average, the engine and FAN repair channels will not be 100 percent utilized. The simulation indicates the HPC, HPT, and LPT service channels have little or no room for mobilization and are at 100 percent utilization after 1095 days.

V. CONCLUSIONS AND RECOMMENDATIONS

The focus of this thesis has been on the effects that depot engine repair consolidation will have on NADEP JAX's F404 engine and module repair operation. Using queueing theory and simulation, the investigation looked at the effects of the consolidation in terms of TAT, number of engines and modules in repair, and the service channel capacity utilization before and after the consolidation goes into effect.

The depot streamlining effort has been initiated, and the F404 engine and module depot level repair will be consolidated at NADEP JAX by the end of FY-92. The streamlining and consolidation of Navy depots has come about as a result of the Defense Management Review (DMR) and Defense Management Review Decision (DMRD) 908. The initiatives are part of a joint DoD depot management initiative to save 3.9 billion dollars by the end of FY-95. The DMR initiatives will save DoD money but how will depot repair operations be affected? This thesis attempted to look at the depot operation from an operational view point.

In this thesis, an economic analysis of the consolidation effort was not conducted as that study has been completed by the Planning, Analysis and Evaluation Division personnel at the Naval Aviation Depot Operations Center. The NADOC Planning, Analysis and Evaluation Division economists indicated to NAVAIR and the Defense Depot Maintenance Council that in the short run (five years) the consolidation would not save money, but over the long term (twenty years), savings would be realized.

NAVAIR and NADEP JAX indicate that the depots will not receive increased production resources to meet the increased work load. This thesis centered on the repair of F404 engines and modules at NADEP JAX, and studied how well NADEP JAX will be able to handle the increased work load without a corresponding increase in production resources.

A. CONCLUSIONS

The results from queueing and simulation model provide insight into what could happen to NADEP JAX's engine and module repair operation. The models indicate the following:

- Prior to consolidating the depot engine repair operation, NADEP JAX was capable of repairing engines and modules in the TAT specified in Appendix B, with capacity utilization available for mobilization or surge requirements.
- Simulating the consolidation of the NADEP NORIS repair workload with NADEP JAX for FY-91 and 92, and Desert Storm, the TAT, number of engines and modules in repair, and the capacity utilization at NADEP JAX all increased.
- By combining the two NADEP's workloads at NADEP JAX for the FY-90, 91, and Desert Storm periods, the simulation indicated that NADEP JAX's queueing became unstable (λ was greater than μ). The graphical plots in Appendix C reflect this when the consolidation goes into effect.

- Simulation results indicate that the FY-92 engine and FAN repair requirements can be completed at NADEP JAX without greatly increasing TAT, WIP, and capacity utilization.
- The simulation for FY-92 indicates that the HPC, HPT, and LPT repair requirements will result in an unstable queueing system at NADEP JAX and that the TAT, WIP, and capacity utilization will rise sharply.

This thesis has estimated the transient behavior of the queueing system at NADEP JAX that would occur as a result of the consolidation of F404 engine and module repair. The pattern of this transient behavior indicates that combining NADEP JAX and NADEP NORIS repair requirements at NADEP JAX without increasing production resources (repair technicians, support equipment, etc.) WIP and TAT increase and little or no capacity is available for surge requirements.

The simulations were conducted to estimate what might have happened at NADEP JAX if the consolidation had occurred in FY-90. It is the author's belief that NAVAIR, ASO, and NADOC would not allow the TAT, and WIP to increase to the extent shown in Chapter IV. The simulation results for FY-92 indicate a potential problem with the HPC, HPT, and LPT repair at NADEP JAX.

Simulating NADEP JAX's engine repair operation and investigating the waiting queue associated with the consolidation provide a tool to investigate the streamlining plan with more than an economic cost analysis. The economic evaluation completed by NADOC indicated that the consolidation of the depots would not yield short term cost savings. The queueing and simulation study indicate that the consolidation of the depots may result in NADEP JAX not being able to meet fleet F404 requirements because of increasing TAT and diminishing available repair capacity. The Defense Depot Maintenance Council indicated that achieving 100% utilization is often a costly approach due to excessive work-in-process and inventories. With all these potentially negative results, one has to wonder why five engine depots were consolidated into three.

B. RECOMMENDATIONS

A problem confronted during this thesis study was a lack of readily accessible depot repair information. TAT had to be used to estimate service time of the engine and modules using Little's flow equations. The actual time to repair an engine or module, is not readily available from a database. To obtain such data, the author had to make assumptions regarding TAT and estimate service time from that measurement.

Therefore, it is recommended that the Navy begin collecting service time of engines and modules repaired at the depot the way the aviation 3M[8] data collection system is used

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[8] The 3M data system is used by U.S. Navy aircraft squadrons and AIMD's to record information regarding maintenance performed on aircraft and aircraft components. Information concerning the type/model/series of equipment, actual repair, parts used to repair the component, and technician information is collected on a Maintenance Action Form. The information is then entered into a central database for future use.

to document service time accumulated on engines repaired at the Aircraft Intermediate Maintenance Department (AIMD). The data collected can be used for studies like the one conducted for this thesis and for compiling information on the status of the depot repair operation for use by depot production managers, program managers at NAVAIR, and planning and evaluation personnel at NADOC.

Future research may examine the effect that consolidation may have on the F404 engine repair done at the Aircraft Intermediate Maintenance Department (AIMD). CDR Heilman wrote in an AIR-431 Priorities Situation Report (Sitrep) that DoD's depot maintenance capacity had been redefined as a result of the DMR initiatives. Specifically, there was an overall excess of industrial maintenance capacity prior to Fy-92 and the future defense depot maintenance workload trend would be decreasing. As CDR Heilman (1991b, 1) pointed out,

> "...barring any unforeseen circumstances, there is going to be less depot work in the future..."

According to Howard (1991), the Navy will continue to procure F404 engines and modules. As the Navy inventory of F404 engines and modules continues to grow, more depot level repair may be required. Unfortunately the depot capacity needed to do this repair, as the findings of this study show, may not be available. If F404 engine and module repair requirements are higher than the forecast and total depot capacity is reduced, more workload will be placed on the intermediate maintenance activities and result in a negative impact on fleet readiness. The AIMD may not have the capacity (i.e., match engine workload with available engine repair capacity) to meet fleet needs. The requirement to repair engines and modules increase as more engines enter the Navy inventory. What greater workload will be put on the AIMD?

If NAVAIR and ASO are planning to have the AIMDs repair a higher percentage of engines, what new criteria, if any, will have to be imposed to ensure fleet readiness is not affected? Perhaps new instructions will need to be written to ensure equitable repair work load is scheduled across all repair activities. AIMD's for example, could be identified to do all engine and module repair and the depots would be used for engine and module engineering investigations. Engineering investigations occur as a result of catastrophic engine failures, poor engine performance that cannot be fixed at the squadron or AIMD, or foreign object damage (an object drawn into an operating engine that severely damages the engines stator and rotor blades). The engineering investigations would be the only work load requirement for the depot.

The simulation models presented in this thesis can be used as a basis to find optimal resource levels required to maintain readiness. The resources at the depots can be simulated and the effectiveness of different production scenarios can be examined. NADEP production supervisors, program managers at NAVAIR, and NADOC planners can use simulation to help in their decision making process to find the optimal level of repair capacity given a specific workload requirement.

One final recommendation is to incorporate more simulation modeling when researching changes of the magnitude of the engine depot consolidation. A significant amount of information can be quickly analyzed and different scenarios analyzed using simulation techniques. Simulation can also facilitate the decision making process by investigating and evaluating measures of effectiveness of complex systems.

DMRD 908 initiatives are a reality. The consolidation of certain functions at the depots is taking place. What is required now is more sensitivity analysis on what can happen to TAT and WIP under various scenarios. The modeling techniques used in this thesis can be used to conduct sensitivity analysis on the impacts of consolidation on the readiness of various Naval aircraft and engines currently repaired at Naval depots.

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APPENDIX A

This appendix describes the interarrival data used in this thesis. Induction data was received from the engine production supervisors at NADEP JAX and NADEP NORIS for the 1st quarter of FY-90 through the 3rd quarter of FY-91.

A. FY-90 AND 91 INTERARRIVAL DATA

TABLE A.1 NADEP JACKSONVILLE INDUCTIONS FROM 1st QUARTER 1990 (1Q90) TO 3rd QUARTER 1991 (3Q91)

Nomen	1Q90	2Q90	3Q90	4Q90	1Q91	2Q91	3Q91
Eng	17	23	17	26	35	19	10
FAN	30	11	23	21	28	23	22
HPC	30	22	26	9	21	16	14
HPT	1	4	5	3	16	9	6
LPT	3	3	2	3	1	8	6

TABLE A.2 NADEP NORTH ISLAND INDUCTIONS FROM 1st QUARTER 1990 (1Q90) TO 3rd QUARTER 1991 (3Q91)

Nomen	1Q90	2Q90	3Q90	4Q90	1Q91	2Q91	3Q91
Eng	20	17	20	26	3	19	9
FAN	10	19	6	15	15	24	10
HPC	12	15	7	13	10	23	12
HPT	5	9	7	6	4	9	9
LPT	2	3	4	5	6	2	2

From the induction information, mean interarrival time was determined for two periods of time. The time periods were: 1) a period that included all quarters from 1st quarter 1990 to the 3rd quarter 1991; and 2) a period that covered "Desert Shield/Storm" (4th quarter 90 through 2nd quarter 91). The average interarrival time (in days) was computed by summing the total number of inductions for the engine or module being investigated and dividing that number by the total days in the period. For example:

$$\frac{1}{\lambda}=\frac{\sum(1Q90+2Q90+3Q90+4Q90+1Q91+2Q91+3Q91)}{635}$$

Where: 1Q90+2Q90+...+3Q91 are the engine or module inductions per quarter from the first quarter FY-90 through the third quarter FY-91 and, 635 is the total number of days for the period first quarter FY-90 to third quarter FY-91.

The mean interarrival times calculated from this equation for NADEP JAX and NADEP NORIS for the periods specified are shown in Table A.3 and A.4.

TABLE A.3 NADEP JAX MEAN INTERARRIVAL TIME (1/λ)

Nomen	FY 90/91 Comb.	Desert Storm
ENG	4.23 days	3.25 days
FAN	4.02 days	3.75 days
HPC	4.60 days	5.87 days
HPT	14.43 days	9.64 days
LPT	24.42 days	22.50 days

TABLE A.4 NADEP NORIS MEAN INTERARRIVAL TIME ($1/\lambda$)

Nomen	FY 90/91 Comb.	Desert Storm
ENG	5.83 days	6.28 days
FAN	6.61 days	5.00 days
HPC	6.90 days	5.87 days
HPT	12.96 days	14.21 days
LPT	26.46 days	20.77 days

B. FORECAST INTERARRIVAL DATA

The simulation model was used to estimate future TAT and capacity utilization based on engine and module induction forecasts. The forecast requirements were taken from NAVAIR's "Aircraft Engine/Module/Power Section/Gearbox Requirement Forecast: Fiscal Years 1989 through 1993." The forecast was developed by personnel at NAVAIR Code-410 using:

1. Programmed flight hours,
2. Ready for Issue (RFI) spare goals,
3. Prior fleet engine removal rates,
4. Most economical level of repair,
5. Prior repairs on site,
6. Backlogged engines from preceding year,
7. Repair site geographical location,
8. Aircraft model phase in/phase out schedules, and
9. Logistics Manager/Type Commander concurrence.

These nine areas provided planning and estimating personnel at NAVAIR Code 410, current, forecast, and historical information that was used to forecast engine and module repairs. The number of required repairs are considered "anticipated" removals and are used for planning purposes only.

The interarrival times for the FY-92 period are anticipated interarrival times based on future F404 engine and module requirements. The actual interarrival time of F404 engines and modules during FY-92 may differ entirely from the anticipated interarrival times. This is evident in the forecast for FY-90. That forecast indicated an F404 engine repair requirement for NADEP NORIS of 65 engines and for NADEP JAX 44 engines. Actual inductions were 83 engines for NADEP NORIS, and 86 engines for NADEP JAX.

The data from the "Forecast Requirements" document provides individual forecasts for NADEP NORIS and NADEP JAX. The forecasted mean interarrival time will be calculated based on a combination of these requirements.

TABLE A.5 FY-92 FORECAST ENGINE AND MODULE REQUIREMENTS AND MEAN INTERARRIVAL TIMES

Nomen	NORIS REPAIRS	JAX REPAIRS	NORIS $1/\lambda$	JAX $1/\lambda$
ENG	31	26	11.77 days	14.04 days
FAN	37	26	9.86 days	14.04 days
HPC	118	16	8.49 days	9.13 days
HPT	43	16	8.49 days	22.81 days
LPT	33	23	11.06 days	15.87 days

APPENDIX B

This appendix describes the service time data used in this thesis. Repair time data was calculated from TAT or days in process for the F404 engines and modules. The TAT was taken from the NADOC "Financial Performance Summary Reports" for FY-91. This report lists all F404 engines and modules repaired during this period, the TAT for each, and financial data showing the cost to repair.

The repair time was calculated using the following equation:

$$\mu=\lambda+\frac{1}{W} \qquad \text{(B.1)}$$

Only repair time at NADEP JAX was calculated since the repair time at NADEP NORIS is not important to this study. Engine and module repair times were calculated from the average TAT.

Using "LOTUS 123" software, the engine and module TAT times were entered into spreadsheets. The average TAT values were used in Equation B.1, with the arrival rate $1/\lambda$ calculated from interarrival times described in Appendix A. The result of these calculations are:

TABLE B.1 NADEP JAX TURN-AROUND-TIME (TAT) AND REPAIR TIMES

Nomen	Average TAT	FY90 & 91 $1/\mu$	Desert Storm $1/\mu$	FY-92 Forecast $1/\mu$
ENG	52.4 days	3.92 days	3.06 days	5.70 days
FAN	50.0 days	3.72 days	3.06 days	5.19 days
HPC	50.6 days	4.22 days	5.26 days	2.21 days
HPT	51.3 days	11.26 days	8.12 days	5.52 days
LPT	46.0 days	15.95 days	15.12 days	5.71 days

The basic queueing model and the STORM quantitative decision software result in an unstable queueing model when the engines or modules arrive at a greater rate than they can be repaired (i.e. $\lambda > \mu$). This is evident when the interarrival rate for the Desert Storm period is used. For example from Table A.3, the engine interarrival time at NADEP JAX during Desert Storm was 3.25 days. If the engine repair time during the FY-90 and 91 time period was used, (i.e., 3.92 days), with the interarrival time of 3.25 days, engines would be arriving faster than they could be repaired and the queue at NADEP JAX would become unstable. Therefore, to use the queueing equations outlined in Chapter III, the repair time for the engine and modules must be computed based upon the average TAT listed in Table B.1 and interarrival times for specific time periods. The interarrival times for engines and modules are shown in Appendix A Tables A.3 and A.4 and were used to calculate $1/\mu$ using Equation B.1. Table B.2 depicts the repair time based on the increased arrival rate after the consolidation.

TABLE B.2 NADEP JAX REPAIR TIME **$1/\mu$** AFTER CONSOLIDATION

Nomen	FY-90 & 91 $1/\mu$	Desert Storm $1/\mu$
Eng	2.34 days	2.06 days
FAN	2.41 days	2.05 days
HPC	2.62 days	2.77 days
HPT	6.08 days	5.16 days
LPT	9.96 days	8.75 days

APPENDIX C

Appendix C is contains the of graphs generated from the SIMAN simulation results. The graphs display the transient behavior experienced by the NADEP JAX consolidation simulation model.

The graphs are displayed by time period. The first group of graphs (Figure C.1 through C.8) display the estimated transition behaviors for the period FY-90 and 91. The second section (Figure C.9 through C.16) displays graphs for the Desert Storm period, and the third section (Figure C.17 through C.24) shows the transition behaviors for the FY-92 forecast.

A. TRANSITION PATTERNS FY-90 AND 91

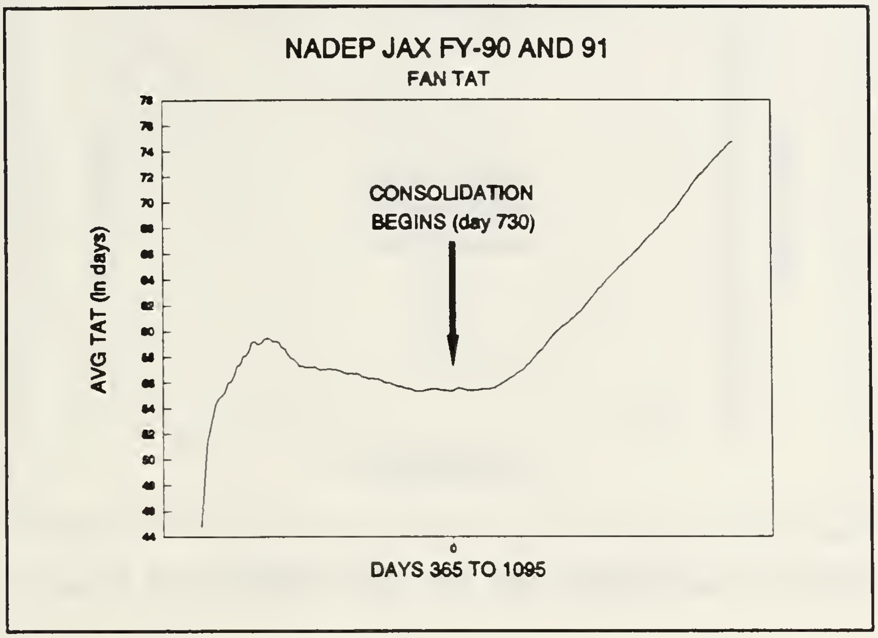

Figure C.1 NADEP JAX FAN TAT FY-90 and 91

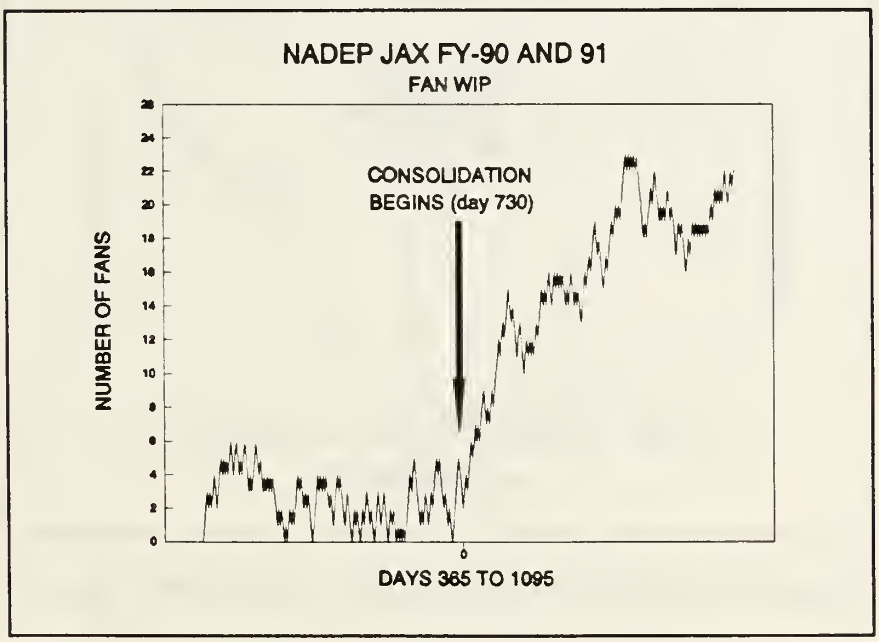

Figure C.2 NADEP JAX FAN WIP FY-90 and 91

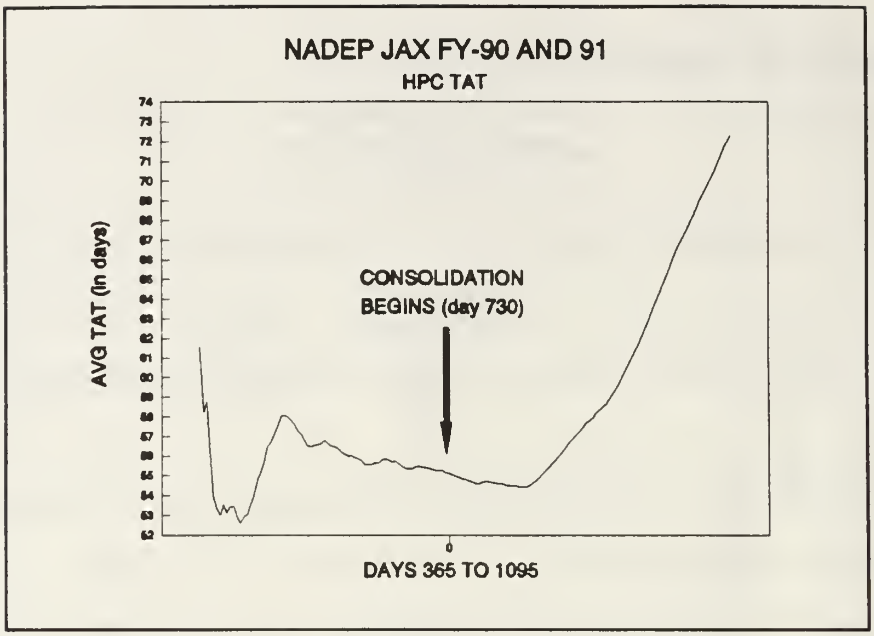

Figure C.3 NADEP JAX HPC TAT FY-90 and 91

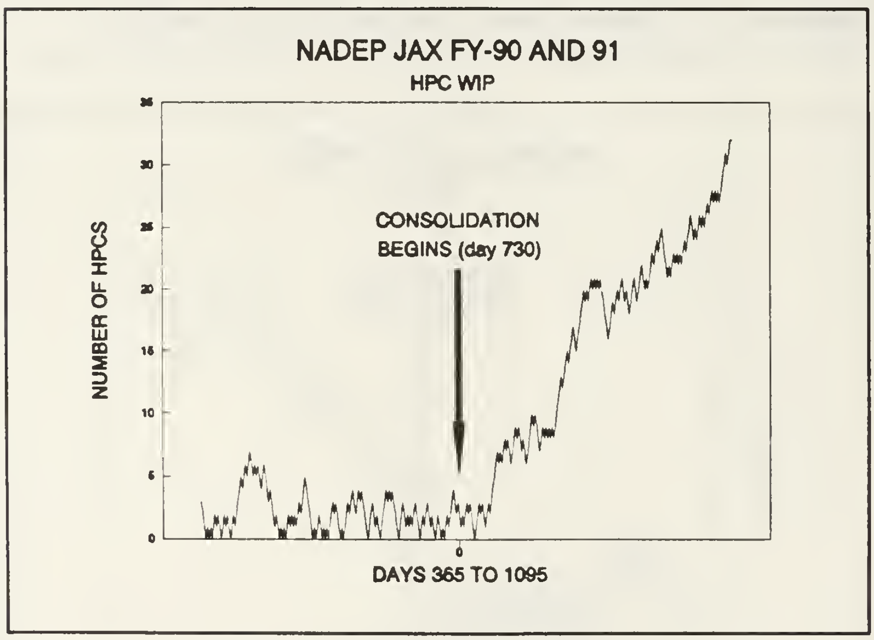

Figure C.4 NADEP JAX HPC WIP FY-90 and 91

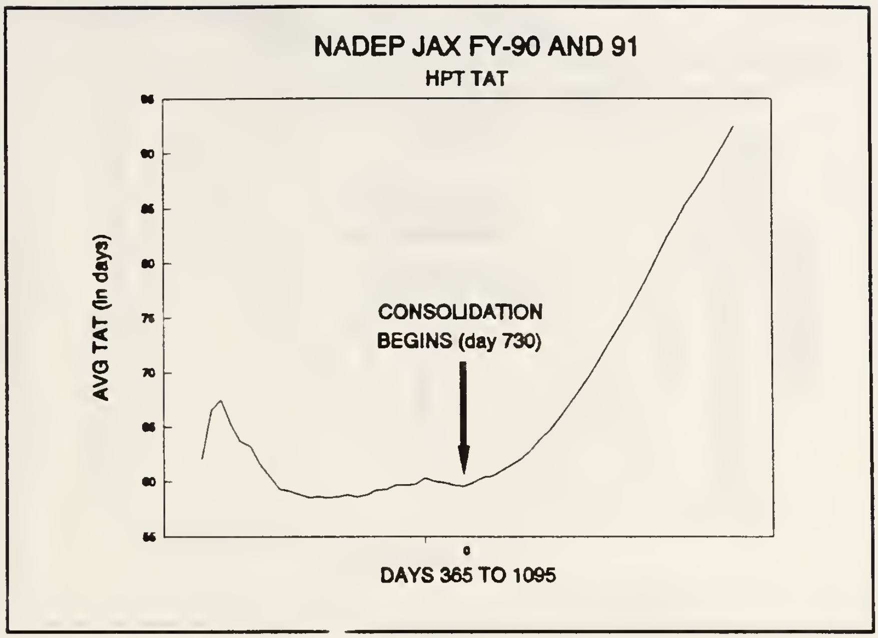

Figure C.5 NADEP JAX HPT TAT FY-90 and 91

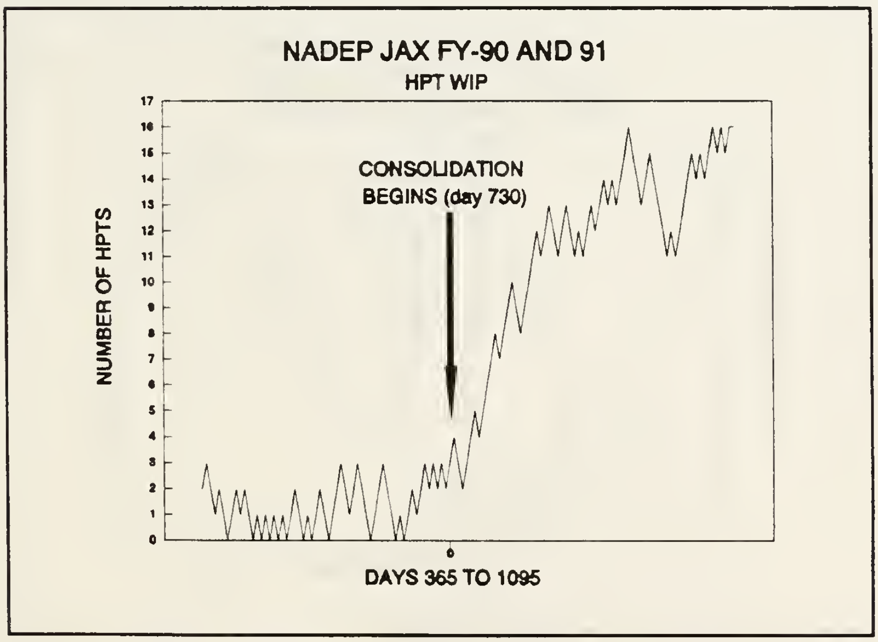

Figure C.6 NADEP JAX HPT WIP FY-90 and 91

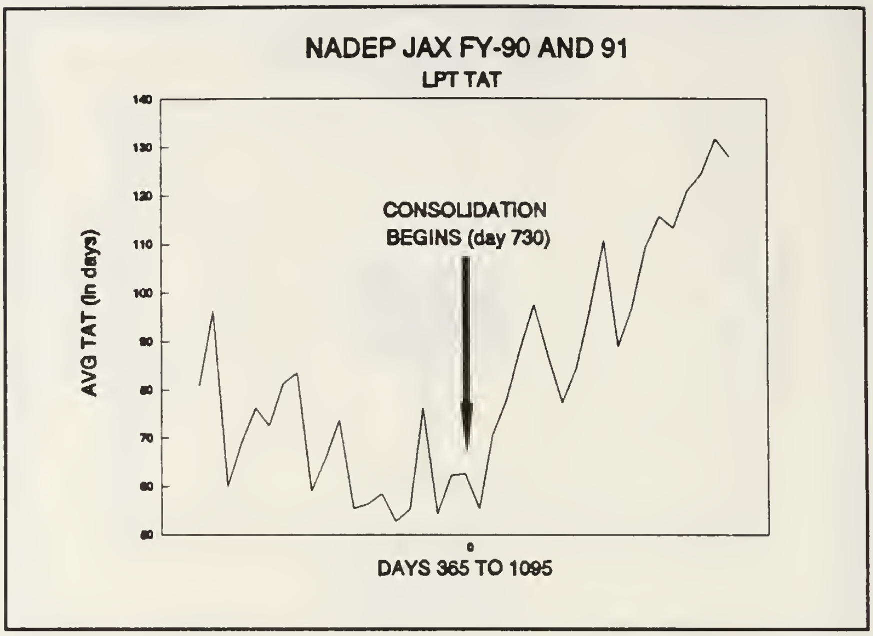

Figure C.7 NADEP JAX LPT TAT FY-90 and 91

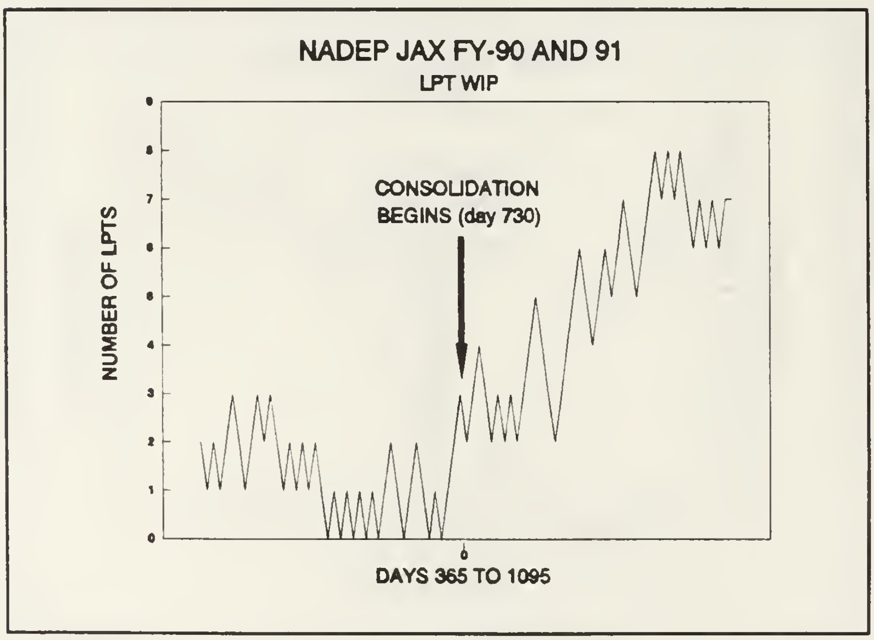

Figure C.8 NADEP JAX LPT WIP FY-90 and 91

B. TRANSITION PATTERNS DESERT STORM

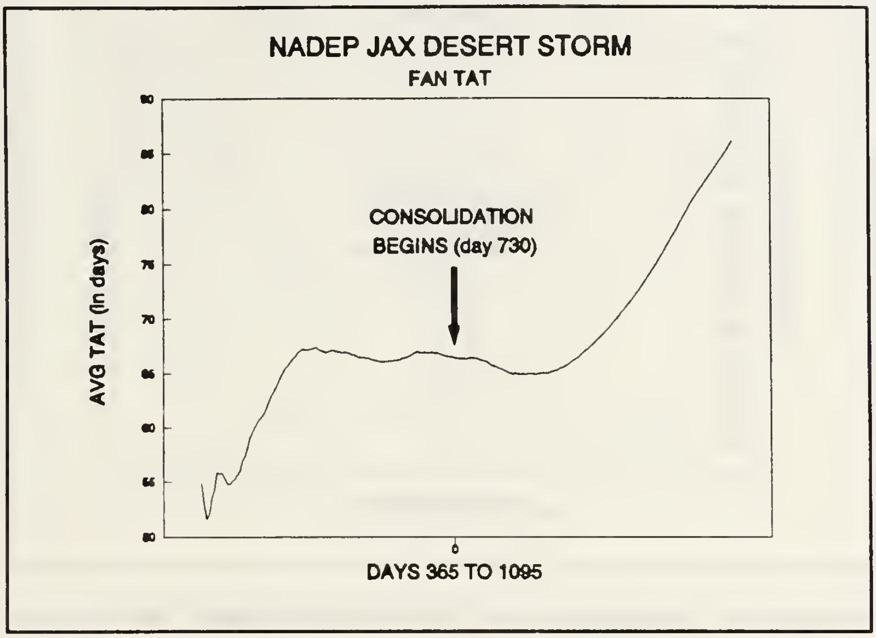

Figure C.9 NADEP JAX FAN TAT Desert Storm

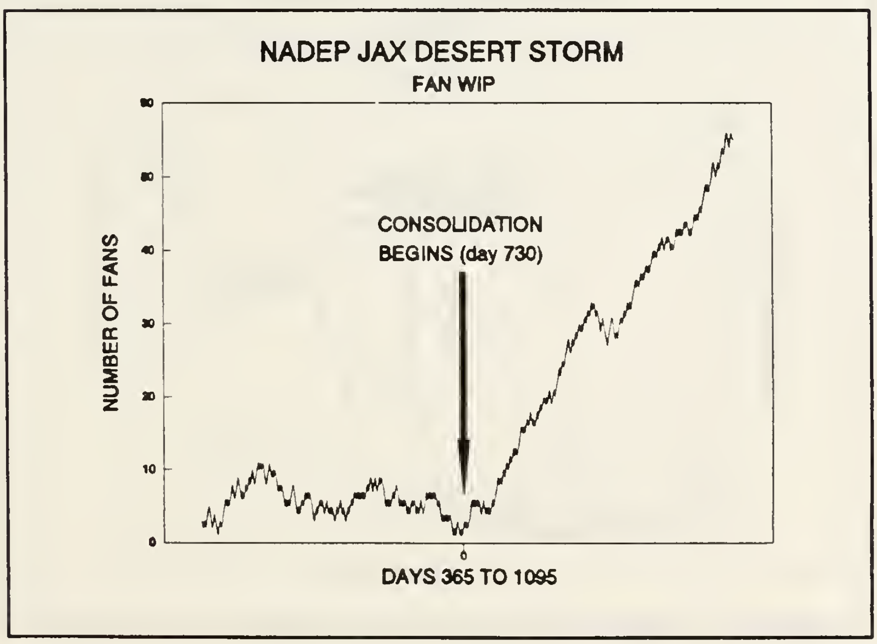

Figure C.10 NADEP JAX FAN WIP Desert Storm

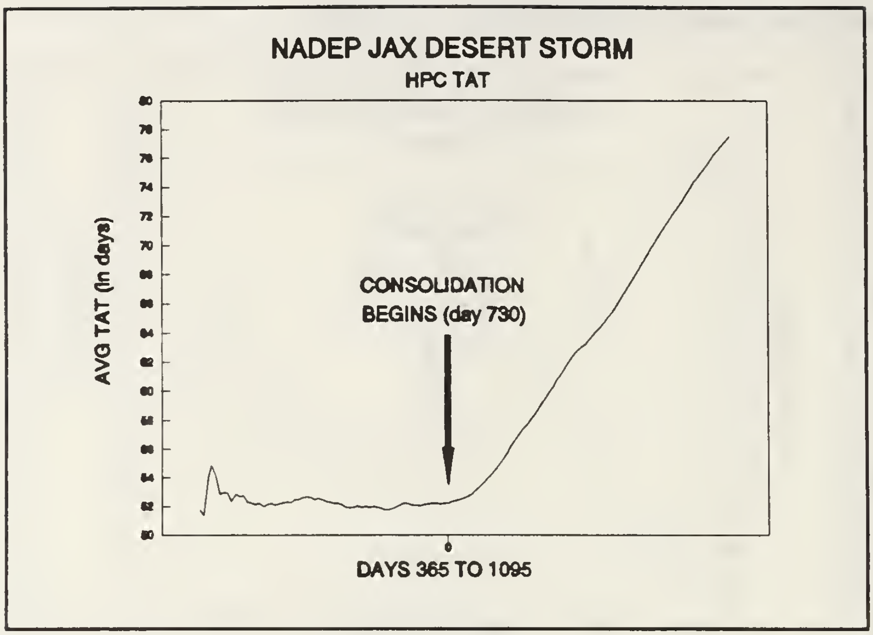

Figure C.11 NADEP JAX HPC TAT Desert Storm

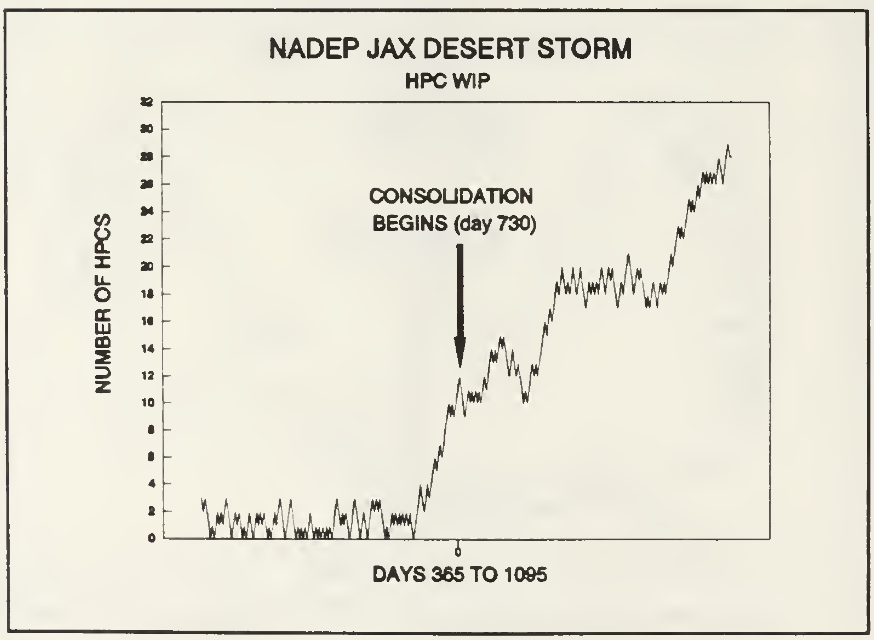

Figure C.12 NADEP JAX HPC WIP Desert Storm

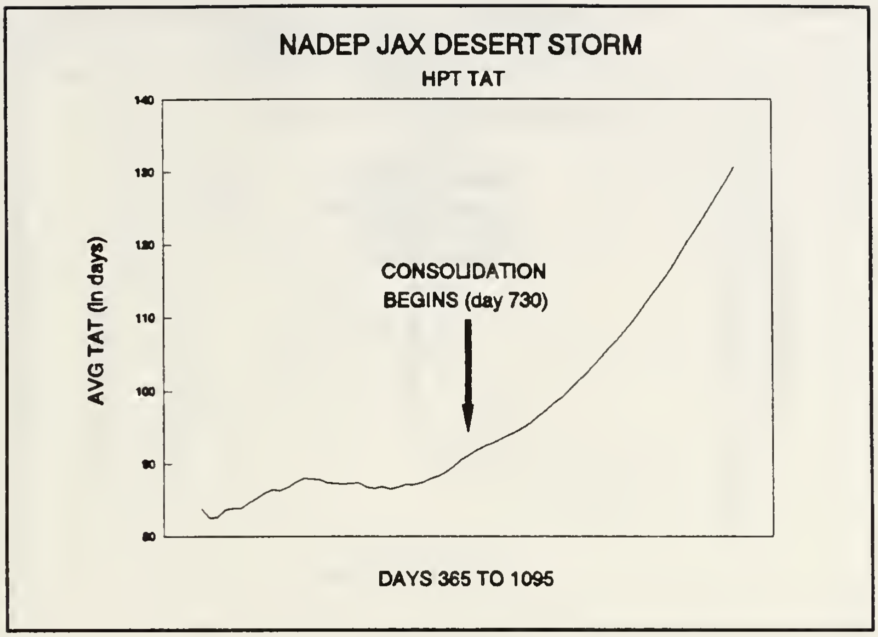

Figure C.13 NADEP JAX HPT TAT Desert Storm

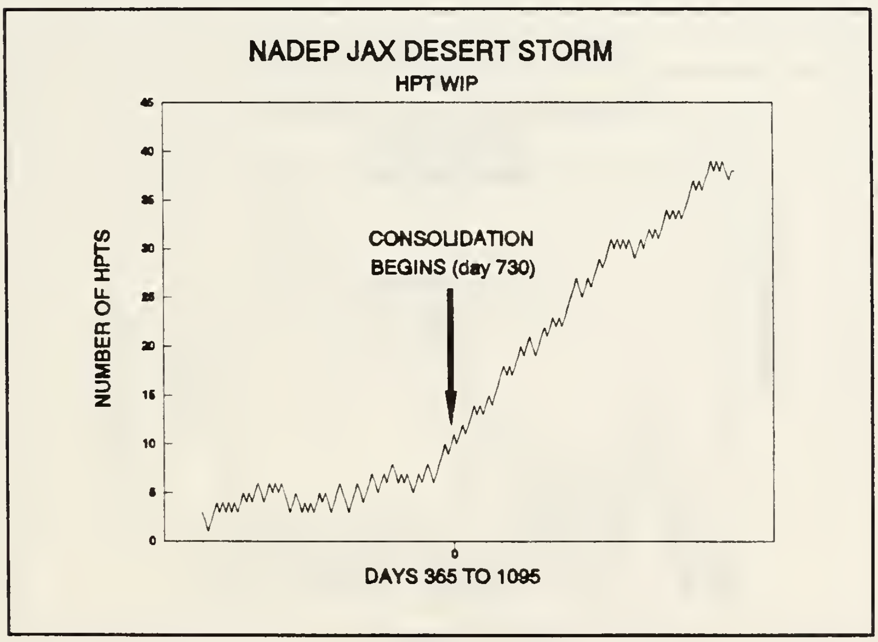

Figure C.14 NADEP JAX HPT WIP Desert Storm

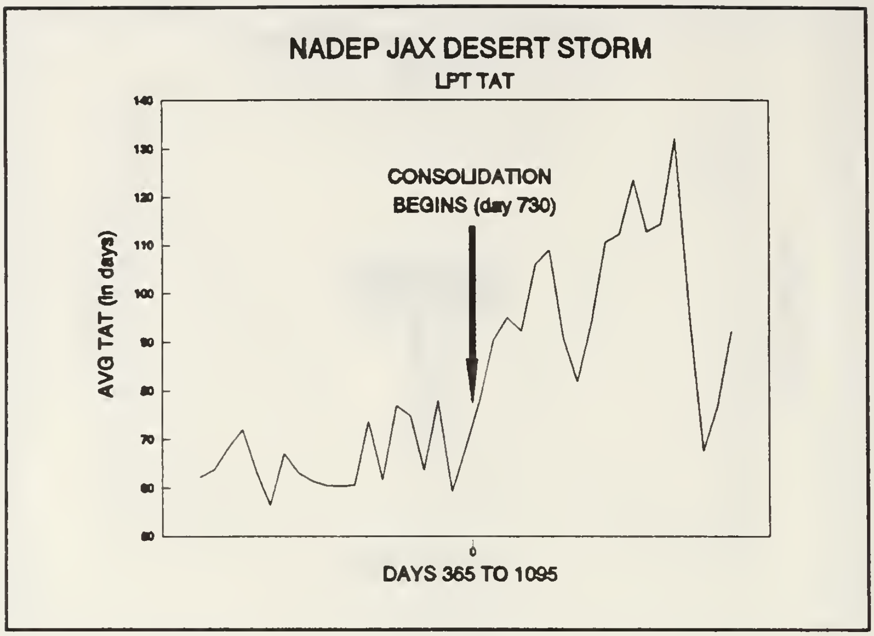

Figure C.15 NADEP JAX LPT TAT Desert Storm

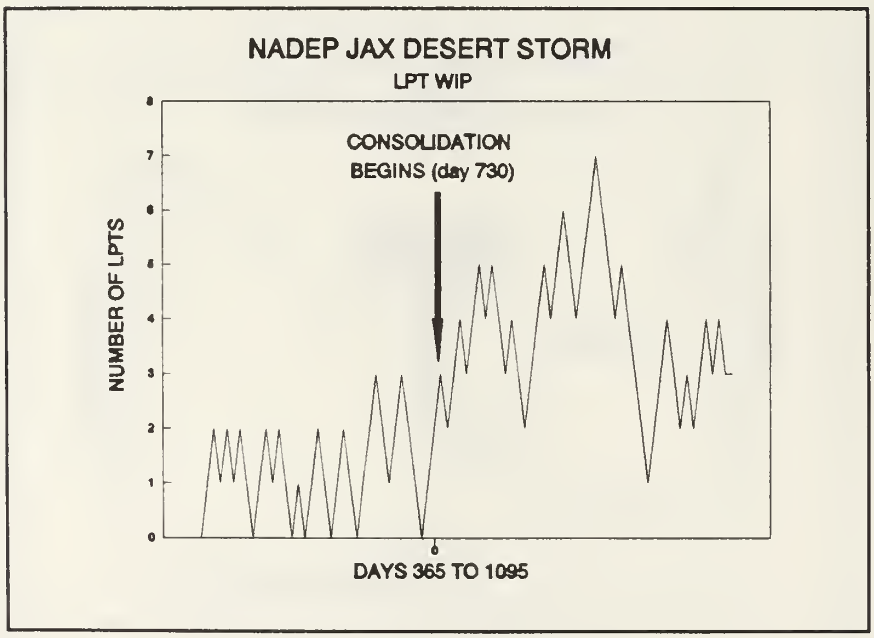

Figure C.16 NADEP JAX LPT WIP Desert Storm

C. TRANSITION PATTERNS FY-92 FORECAST

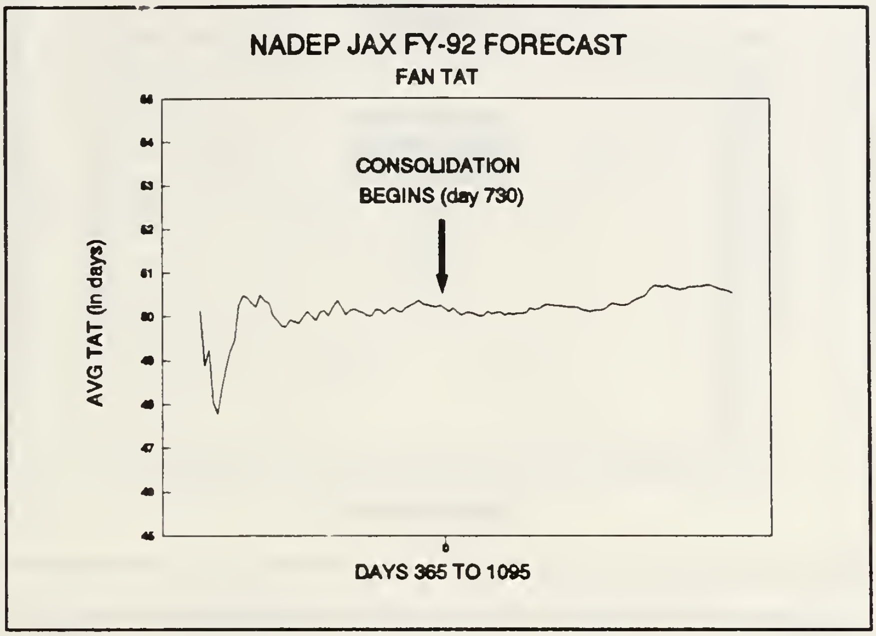

Figure C.17 NADEP JAX FAN TAT FY-92 Forecast

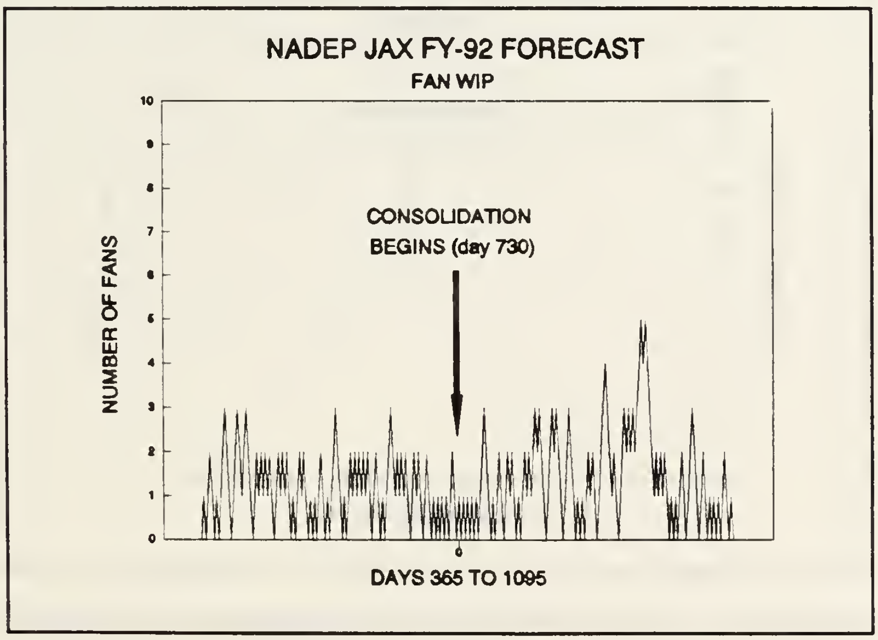

Figure C.18 NADEP JAX FAN WIP FY-92 Forecast

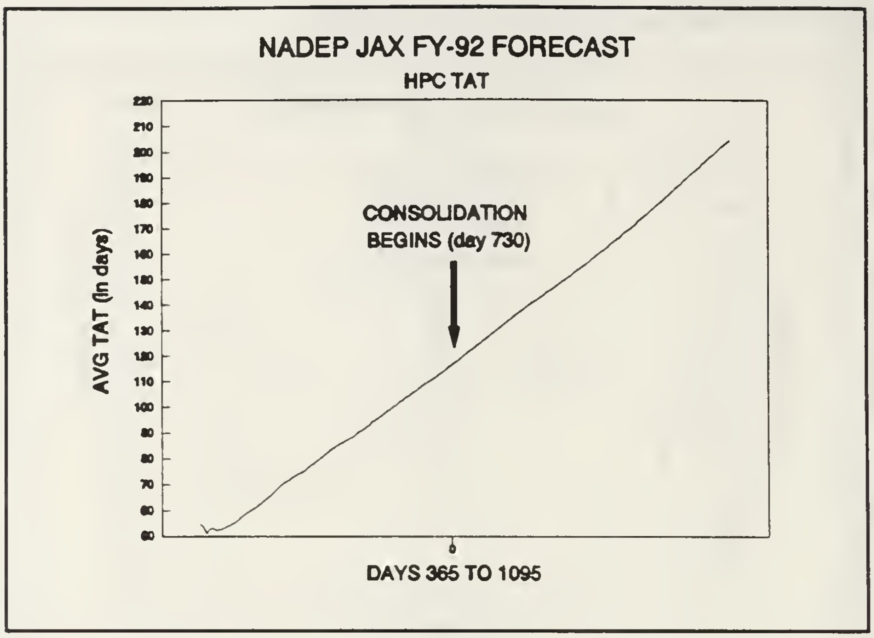

Figure C.19 NADEP JAX HPC TAT FY-92 Forecast

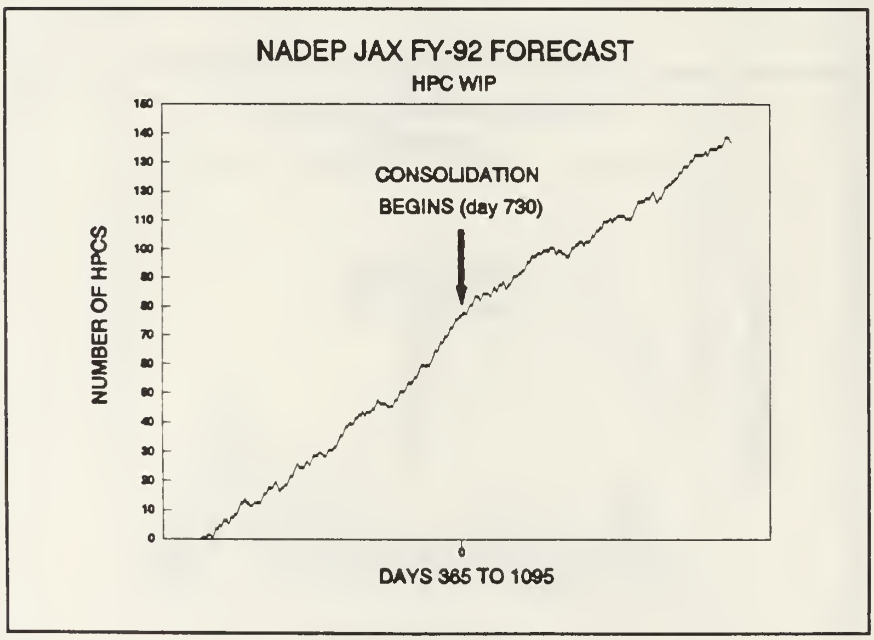

Figure C.20 NADEP JAX HPC WIP FY-92 Forecast

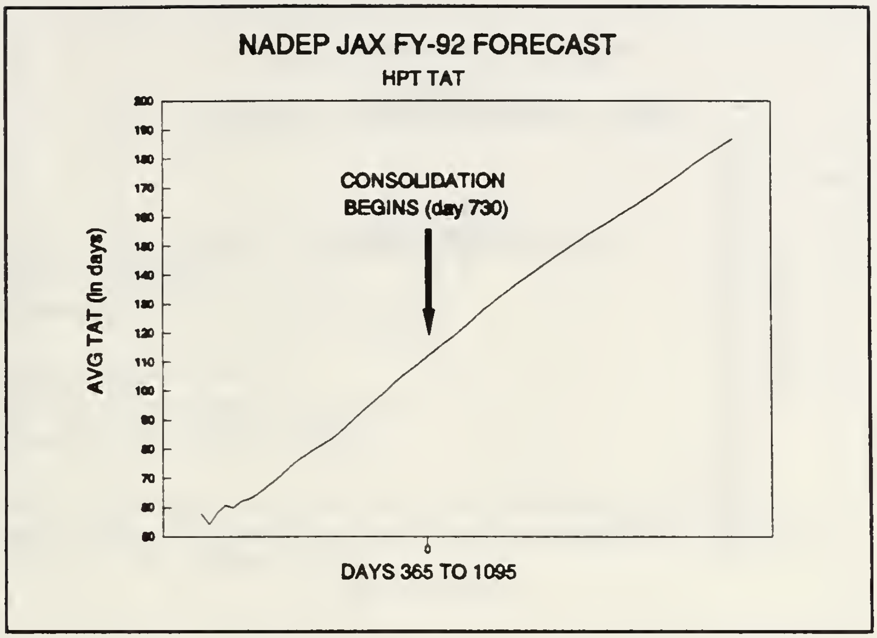

Figure C.21 NADEP JAX HPT TAT FY-92 Forecast

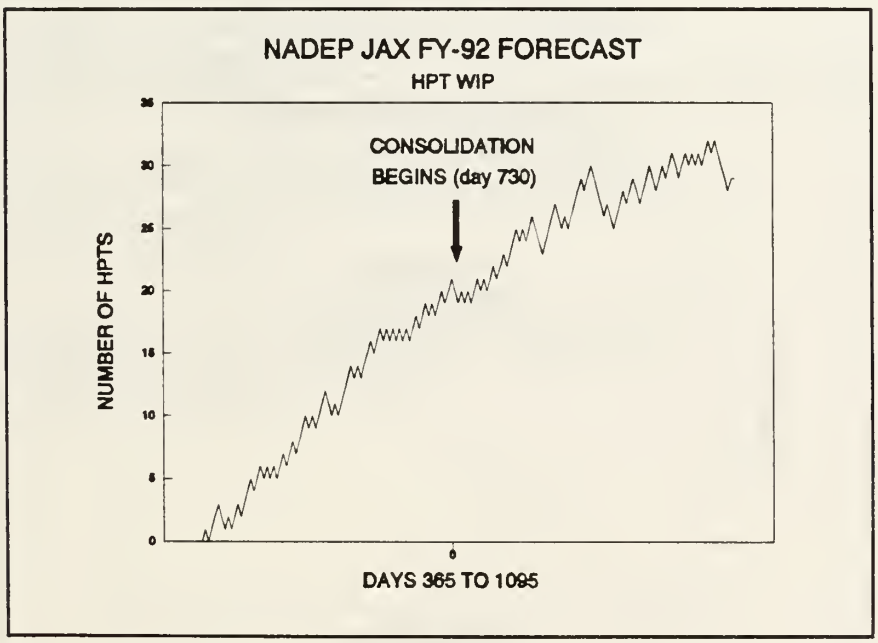

Figure C.22 NADEP JAX HPT WIP FY-92 Forecast

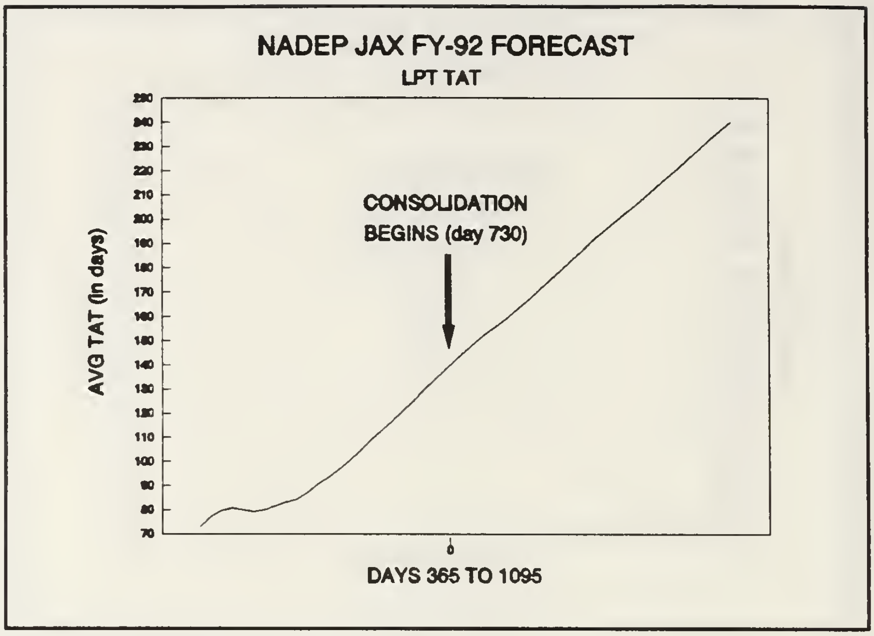

Figure C.23 NADEP JAX LPT TAT FY-92 Forecast

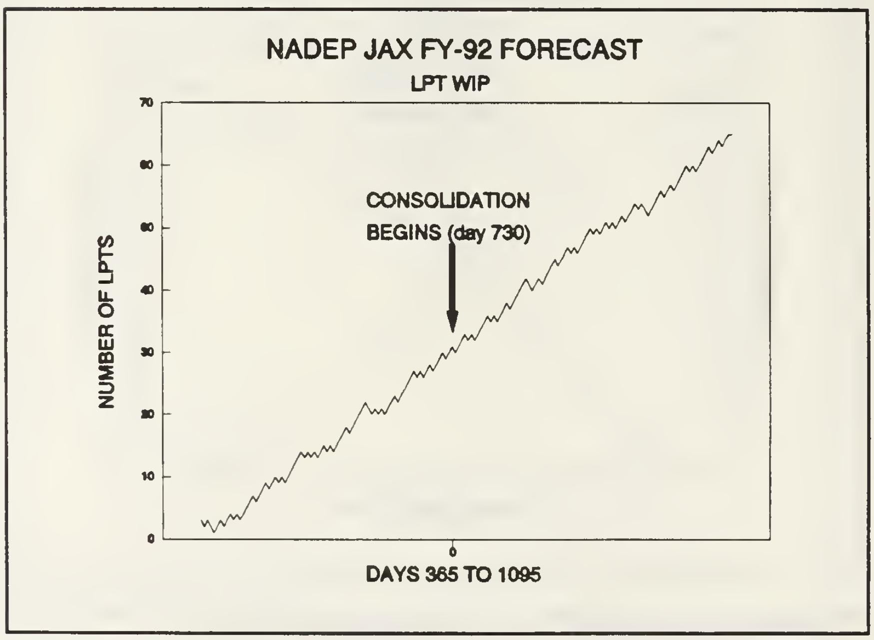

Figure C.24 NADEP JAX LPT WIP FY-92 Forecast

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